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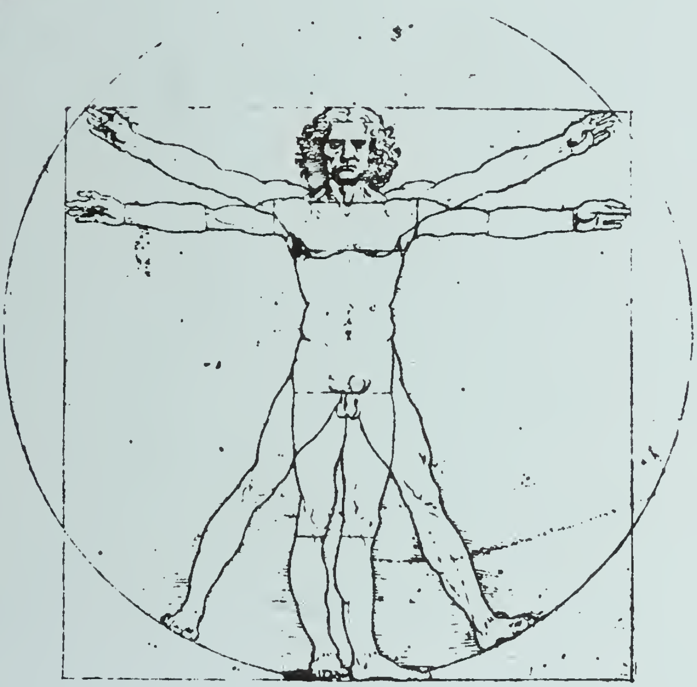

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DEER LODGE VALLEY
DISPERSION STUDY

by

Bruce Nelson
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AIR QUALITY BUREAU

ENVIRONMENTAL SCIENCES DIVISION
DEPARTMENT OF HEALTH AND ENVIRONMENTAL SCIENCES
HELENA, MONTANA 59601

OCTOBER, 1980

FOREWORD

This is one of a series of technical reports presenting results from the Montana Air Pollution Study (MAPS), a special air monitoring and health effects project of the Air Quality Bureau, Montana Department of Health and Environmental Sciences. The 1977 Montana Legislature provided the MAPS project with $1.07 million for the 1977-79 biennium to improve understanding of how air pollution affects health in Montana. The 1979 Legislature extended the MAPS project to June 30, 1981.

The various MAPS activities have been grouped into five major categories for purposes of project management: Health Effects; Air Quality; Meteorology/Modeling; Emission Inventory; and Statistics and Data Systems. Results from each of these areas are to be presented in a series of reports prepared by the personnel directly involved in each category of MAPS. In addition, an overall technical summary report will be prepared.

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PREFACE

This report, in the Meteorology/Modeling area, presents results of the dispersion study conducted in the Deer Lodge Valley near Anaconda. This study was funded largely by the Anaconda Company as a provision of an agreement with the Air Quality Bureau. Because of the direct relationship with the Montana Air Pollution Study (MAPS), this report was included in the MAPS series. Michael Machler and Harold Robbins of the Air Quality Bureau designed and coordinated the study, while Bruce Nelson, consulting meteorologist, conducted the actual field study.

EXECUTIVE SUMMARY

The Air Quality Bureau, Montana Department of Health and Environmental Sciences, conducted a meteorological study of the southern end of the Deer Lodge Valley in southwestern Montana during 1978-1979. The study was conducted partially under funds provided by the Anaconda Company as a provision of an agreement with the Air Quality Bureau. The study included the use of meteorological instrumentation at two Air Quality Bureau monitoring sites and five Anaconda Company sites. Upper air meteorology was studied for seven months through the use of pilot balloons, temperature sondes, and acoustic radar. Data were obtained on mixing heights, atmospheric stability, and on the height, intensity, and duration of inversions, as well as other related meteorological parameters. All data were reduced to computer format and summarized into monthly and seasonal tables for morning and afternoon periods. This report presents the summarized data, their analysis, and interpretation. Two case studies are included to illustrate typical air polluton events in the Anaconda area. An effort has been made to relate meteorology to air monitoring in the final section of the report.

TABLE OF CONTENTS

PAGE

FOREWORD i
PREFACE ii

EXECUTIVE SUMMARY iii

I. INTRODUCTION 1
    A. STUDY AREA DESCRIPTION 2
    B. STUDY DESIGN AND METHODS 2
II. DISCUSSION AND RESULTS 11
    A. SURFACE METEOROLOGY 11
    B. UPPER AIR METEOROLOGY 12
III. CASE STUDIES 30
    A. CASE I 30
    B. CASE II 40
IV. SUMMARY AND CONCLUSIONS 48

REFERENCES 49

TABLES

PAGE

1. Distances and Directions from Sources to Stations and Population Centers 5
2. Elevations and Relief of Sources, Stations, and Population Centers 6
3. Surface Wind Speed and Direction, Lincoln School Anaconda, 1979. 13
4. Surface Wind Speed and Direction, Highway Junction, Anaconda, 1979 13
5. Holzworth Lapse Rate Categories (Modified) 19
6. Summary of Stable Atmospheric Conditions 25
7. Summary of SO_2 Violations at All Stations 26
8. Stages of Emergency SO_2 Episodes. 30
9. Lincoln School SO_2 Concentration and Wind Behavior 36
10. Highway Junction SO_2 Concentration and Wind Behavior 42
11. Inversions and SO_2 Concentrations 43

FIGURES

PAGE

1. Deer Lodge Valley Topography and Geography 3
2. Ambient Air Monitoring Site 4
3. Monthly Average Mixing Heights, Highway Junction, Anaconda, 1979 17
4. Frequency Summary of Inversions, Highway Junction, Anaconda, 1979 20
5. Mean First Inversion Lapse Rates, Highway Junction, Anaconda, 1979 22
6. Maximum First Inversion Lapse Rates, Highway Junction, Anaconda, 1979 23
7. SO_2 Concentrations as a Function of Wind Direction, Highway Junction, Anaconda, 1979 29
8. Chart of Process Flow, Anaconda Smelter, Anaconda 31
9. Chart of Process Flow, Anaconda Smelter, Anaconda 32
10. SO_2 Concentrations as a Function of Wind Direction, Lincoln School, Anaconda, 1979 34
11. Wind Barbs 38
12. Wind Vectors for 29 August 1979 39
13. Upper Air Wind Speed and Direction. 44
14. Wind Vectors for 24 October 1979 46
15. Smelter Stack Photograph. 47
16. Diagram of Wind Patterns near Smelter Stack 48

I. INTRODUCTION

The Air Quality Bureau, Montana Department of Health and Environmental Sciences, conducted a meteorological study in the Deer Lodge Valley of southwestern Montana from May 1978 through April 1979. Results of the study were presented in a technical report released by the Bureau in July 1979 (Harner, Gelhaus, Roach). Further study of the area from May 1979 through December 1979 is presented in this document.

The Air Quality Bureau study arose from the need for a detailed meteorological characterization of the region around the Anaconda Company's copper smelter at Anaconda, Montana. Several previous investigations of air pollutant emission dispersion near the smelter identified a lack of upper air and surface meteorological data. The Department of Earth Sciences at Montana State University developed several diffusion models of the area in an attempt to simulate pollutant dispersion and ground level concentrations (Heimbach, 1977). During a two-month period in 1976, the Environmental Monitoring and Support Laboratory of the U.S. Environmental Protection Agency (EPA) conducted airborne measurements of air pollutants from the smelter plume in the Anaconda area (Johnson, 1973). In addition, an investigation commissioned by the Anaconda Company compared actual ground level concentrations of sulfur dioxide (SO_2) to concentrations of the pollutant predicted by diffusion models (Environmental Research and Technology, 1978). These previous studies and reports demonstrated a need for a beneficial meteorological data base.

The Deer Lodge Valley Dispersion Study was conducted to provide the necessary data base for modeling assessments and to identify meteorological conditions associated with high sulfur dioxide concentrations that can be hazardous to human health, property, and the natural environment.

A. Study Area Descripton

The study area is located at the southern end of the Deer Lodge Valley in southwestern Montana, near the town of Anaconda. The valley is about 50 kilometers long, north to south, and 17 kilometers wide, east to west, while the mountain relief to the east of the valley is about 900 meters and to the west and south about 1500 meters. The population of the valley is about 15,000. Figure I depicts the topographic and geographic features of the area. Spatial relationships of major topographic features, emission sources, monitoring stations and population centers are shown in Figures 1 and 2, and listed in Tables I and II.

Various topographic features affect the area's meteorology. The mountainous character of the area promotes frequent valley temperature inversions, which trap pollutants for short periods and infrequently for extended periods. Several wind drainages can be found in the area, including the Mill Creek Valley, Warm Springs Creek Valley, and the Deer Lodge Valley. These three wind drainages intersect near the smelter and result in complex wind patterns.

The general climatology of the Anaconda area is typical of the northern Rocky Mountain region. The average annual temperature is 42.4°F (5.8°C). January, the coldest month, averages 22.3°F (-5.4°C), while July, the warmest month, averages 65.6°F (18.7°C). The annual precipitation in Anaconda is 14.32 inches (364 mm). February is the driest month averaging 0.63 inches (16 mm), while June is the wettest at 2.74 inches (69.5mm) (NOAA, 1973).

B. Study Design and Methods

Data collection involved eight air quality/meteorology monitoring stations. The Air Quality Bureau operated two sites, one at Highway Junction at the junction of U.S. 10A and Montana 48, and one at Lincoln School situated to the west of downtown Anaconda (Figure 2). The Highway Junction site contained the upper air monitoring instrumen-

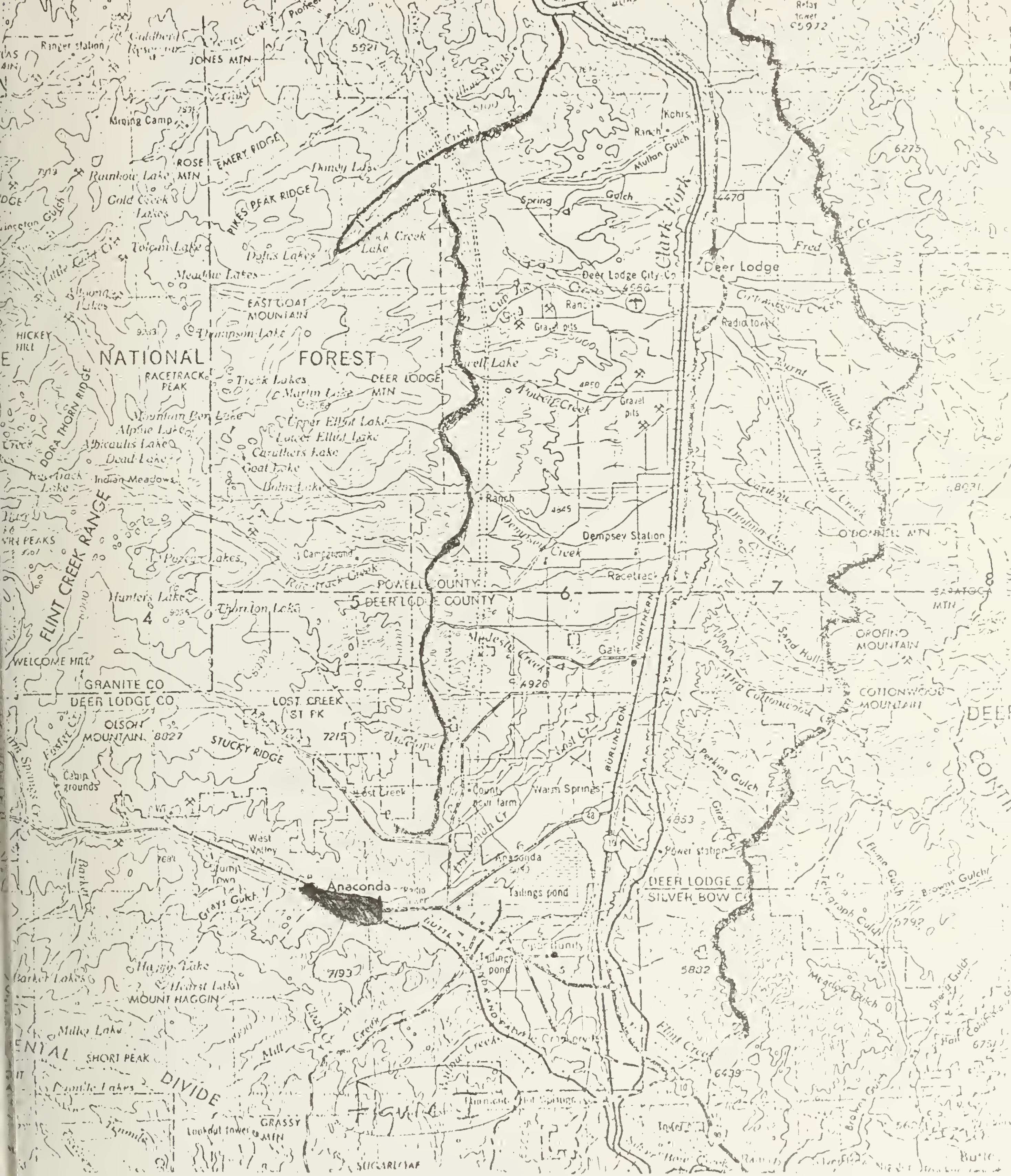


FIGURE 1
Deer Lodge Valley Topography
and Geography

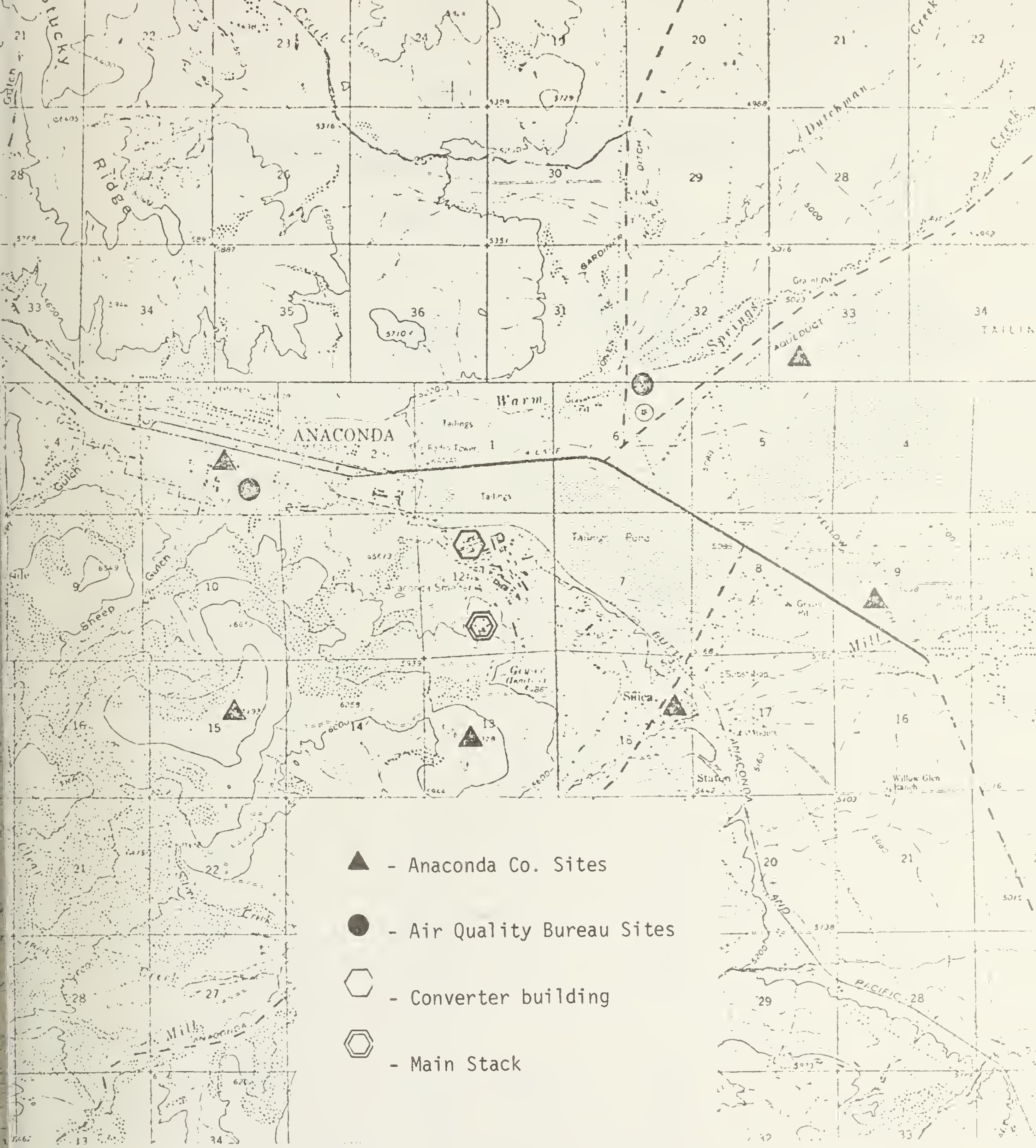


FIGURE 2
Ambient Air Monitoring Sites

TABLE 1

DISTANCES AND DIRECTIONS FROM SOURCES TO STATIONS AND POPULATION CENTERS

(See Figure 1)

Station and Source	Distance Miles	Km	Angle from North to Station, clockwise (Degrees)	Wind Angle Which Could Impact Station
Main stack to:				
A (State Highway Jct.)	2.25	3.62	30	210
B (State Lincoln School)	1.90	3.05	302	122
Converters to:				
A (State Highway Jct.)	1.85	2.98	42	222
B (State Lincoln School)	1.60	2.57	285	105
Main Stack to:				
1 (Water Office)	2.25	3.62	303	123
2 (Airport)	3.15	5.07	49	229
3 (Opportunity)	2.85	4.59	87	267
4 (Mill Creek)	2.15	3.50	197	17
5 (Weather Hill)	0.85	1.36	185	5
6 ("C"Hill)	1.95	3.13	252	72
Main Stack to:				
Gregson Hot Springs	6.81	10.95	133	313
Opportunity	3.90*	6.28	91	271
Warm Springs	7.70*	12.39	50	230
Galen	10.85*	17.46	36 (39-converter)	216(219 conv.
Deer Lodge	21.70*	34.92	24	204
Anaconda	2.40*	3.86	299	119

*City center

TABLE II

ELEVATIONS AND RELIEF OF SOURCES, STATIONS AND POPULATION CENTERS

Stations and Sources	Elevation above sea level		Relief Highway Junction=0	
	meters	feet	feet	meters
Highway Junction	1,528	5,014	0	0
Lincoln School	1,615	5,300	286	87
Water Office	1,625	5,332	318	97
C-Hill	2,185	7,170	2,156	657
Weather Hill	1,944	6,379	1,365	416
Mill Creek	1,681	5,515	501	153
Airport	1,527	5,009	-5	01.5
Opportunity	1,537	5,044	30	9.1
Top of Main Stack	1,933	6,342	1,328	405
Top of Converters	1,672	5,484	470	143
Anaconda	1,600	5,250	236	72
Deer Lodge	1,402	4,600	-414	-126
Opportunity	1,542	5,000	-14	- 4
Warm Springs	1,463	4,800	-214	-65
Fairmont Hot Springs	1,579	5,180	166	51
Galen	1,463	4,800	-214	-65

tation and served as the "ground level" point when referring to winds, temperatures, or inversions at distances "above ground level." The Anaconda Company erected and maintained the remaining six sites.

Meteorological instrumentation at the two Air Quality Bureau sites included the following:

Highway Junction

MRI wind speed and direction;

Aerovironment acoustic radar, model # 300C monostatic mode;

Weather Measure - pilot balloons;

Aero Aqua - temperature sondes.

Lincoln School

Climatronics - model # F-460 -wind speed, wind direction, dewpoint, temperature, solar radiation;

Volzmeter - turbidity.

Continuous records of surface wind speed and wind direction were collected at each station throughout the study period. Both the Lincoln School station and the Highway Junction site were equipped with anemometers for this purpose.

Thirty-gram, helium-filled balloons were used to sample meteorological conditions throughout the atmosphere. These balloons were precalibrated for a constant ascent rate, tracked with a single theodolite, and equipped with a small, inexpensive temperature thermistor and battery-operated transmitter to record the atmosphere's continuous temperature profile. Pilot balloons were released one-half hour after sunrise, when atmospheric motion is normally at a minimum (and stability is greatest), and in the afternoon (1400 MST) when atmospheric motion is normally at a maximum (and stability is least). During June, July, August and December, balloons were released three days a

week, while in September, October and November, they were released five days a week, as part of the Air Quality Bureau's smoke management program.

The acoustic radar located at Highway Junction was used to determine the atmosphere's degree of stability or instability. This instrument transmits a sound pulse vertically into the atmosphere where it is reflected back by temperature variations and microscale turbulence. A ground-based receiver records the reflected sound pulse and provides a continuous record of stable layers in the lowest 1000 meters of the atmosphere.

Incoming solar radiation intensity and duration were monitored continuously with a pyranometer located at the Lincoln School site. Solar radiation influences atmospheric turbulence and can promote photochemical reactions among air pollutants. (Atmospheric particulate pollution may attenuate solar radiation.) This atmospheric turbidity is measured as the amount of light able to penetrate a cloudless atmosphere. Turbidity measurements were made at Lincoln School with a handheld sun photometer (Volzmeter). Readings were taken when the sun was unobscured by clouds at 0900, 1200 and 1500 MST.

The data from the pilot balloons, temperature sondes, acoustic radar, Volzmeter, and anemometers were coded into computer format and forwarded to Helena where analysis and storage were completed through the Montana Air Pollution Study's meteorological data system. Information yielded by the various monitoring instruments included the following:

Acoustic Radar

*Atmospheric Stability - (stable, unstable, neutral);

Meteorological events - precipitation, frontal passage;

*Inversion Type - subsidence, radiation, frontal;

*Inversion Base Height - height from ground level to the base of the inversion;

*Inversion Thickness - thickness of inversion from base to top of the inversion;

Inversion formation time - time of day inversions formed;

Inversion lift time - time of day inversion lifted; and

Inversion angle of ascent - rate of rise of inversion as it lifted.

Pilot Balloons

*Wind speed - first two thousand meters through the atmosphere;

*Wind direction - first two thousand meters through the atmosphere; and

*Average wind speed through mixed layer.

Temperature Sondes

*Inversion base - height from ground level to inversion base;

*Inversion thickness - thickness from inversion base to top;

*Inversion strength - related to inversion lapse rate; and

Inversion and non-inversion lapse rates.

Surface wind speed and direction

*Average wind speed and direction for months, seasons, and year; and

*Maximum and minimum wind speeds.

Solar Radiation

*Turbidity of atmosphere as affected by air pollution.

A more complete explanation of meteorological sampling methods and data analysis was presented in a preliminary meteorological summary report (Gelhaus, et al. March 1979).

The Air Quality Bureau also had the following ambient air quality monitoring equipment at both Highway Junction and Lincoln School:

Highway Junction

Phillips S02 monitor - model #9700;

High-volume particulate sampler model #GMW-2000.

Lincoln School

Dasibi ozone analyzer - model #A1003.

Beckman total hydrocarbon analyzer model #109;

Teco SO_2 analyzer - model #43;

Sierra dichotomous particulate sampler - model #244;

RAC membrane particulate sampler; and

*These parameters are stored in the AQB computer files.

A complete description of the data collection and analysis methods for the ambient air monitoring equipment was presented in two Air Quality Bureau publications: "A Network Review of Montana's Ambient Air Monitoring" (Maughan, Sternberg, April 1977); and "Air Monitoring Instrumentation" (Robbins *et al*. 1979).

Two high-volume particulate samplers - model #GMW-2000.

II. DISCUSSION AND RESULTS

A. Surface Meteorology

Wind Direction

Data on surface wind direction collected at Highway Junction and Lincoln School in Anaconda indicate that the prevailing winds are southwesterly. Tables III and IV list the average wind speed, wind direction, and maximum wind speed on a monthly, seasonal, and annual basis. A comparison of the monthly average wind directions reveals that the winds measured at Lincoln School are consistently more westerly than are the winds measured at Highway Junction. This phenomenon is most likely due to the westerly drainage winds from Warm Springs Creek Valley, which are most noticeable during the warm summer months.

Wind Speed

Data on surface wind speed collected at Lincoln School and Highway Junction show a very sharp variation in average wind velocity at each station. Highway Junction wind velocities averaged between two and eighteen times greater than those found at Lincoln School for any given month. The lower wind velocities at Lincoln School probably were due to the station's particular location in the Warm Springs Creek Valley, which protected the site, in contrast to the location of the Highway Junction Site in a broad flat portion of the Deer Lodge Valley. The low wind velocities at Lincoln School denote the probability that stagnant air could settle into the area, resulting in the buildup of air pollution due to lack a of atmospheric mixing and dispersion. The relatively high mean and maximum wind velocities at Highway Junction tend to eliminate high pollution concentrations due to stagnation.

Maximum wind velocities at both stations occurred during the winter and late fall, while the lowest maximum wind velocities for both stations occurred during the summer. This trend also is verified for the average wind velocity data.

B. Upper Air Meteorology

Upper air meteorological characteristics were measured through the use of pilot balloons, temperature sondes, and acoustic radar. The following analysis of upper air includes wind direction, wind speed, temperature profiles, mixing heights, inversions, and stability analysis. Most of these parameters are examined as to morning and afternoon characteristics with respect to monthly, seasonal, and annual time frames.

Wind Direction

Wind direction for the Anaconda area is examined here with respect to two "critical heights," which correspond to the top of the main stack at 405 meters above ground level (AGL) and the top of the converters at 143 meters AGL. Five hundred meter AGL and 200 meter AGL values are used in the discussion because they represent the nearest values, yielded by computer analysis, to the actual height of the stack and converters.

At the surface, the wind was most often westerly in the mornings at 36.2 percent of the time on an annual basis. The second most common direction for morning winds was southwestly at 12.4 percent. The afternoon winds came most frequently from the north at 14.2 percent, with the east-northeast second at 9.7 percent annually. Seasonally, the winter morning winds were most usually westerly at 17.7 percent and secondarily out of the south at 16.1 percent. Afternoon winter winds were predominantly southwesterly with 15.9 percent frequency. Fifteen percent of the spring winds were from the south. Overall, 40 percent of the spring morning winds came from the southern quadrant.

Table III Surface Wind Speed and Direction

Lincoln School, Anaconda, 1979

Month	Ave. Wind Speed m/s	Ave. Wind Direction	Maximum Wind m/s
Jan	1.7	223	8.4
Feb	1.5	207	4.2
Mar	1.7	202	4.0
Apr	1.3	213	3.6
May	1.3	198	3.6
June	0.2	278	0.9
July	2.7	276	
Aug.	0.5	211	28
Sept.	3.1	290	
Oct.	2.6	305	
Nov.	2.1	223	4.3
Dec.	3.6	240	
Winter	2.3	223	
Spring	1.4	204	
Summer	1.1	255	
Autumn	2.6	273	
Annual	1.9	239	

Table IV Surface Wind Speed & Direction

Highway Junction, Anaconda, 1979

Month	Ave. Wind Speed	Ave. Wind Direction	Maximum Wind
Jan	2.4	189	11.4
Feb	4.6	202	13.6
Mar	3.1	185	11.6
Apr	3.6	216	8.9
May	4.3	220	10.5
June	3.6	218	12.0
July	3.1	185	11.6
Aug	3.1	187	9.8
Sept	3.3	225	8.0
Oct.	2.7	214	9.8
Nov			
Dec			
Winter			
Spring	3.7	207	10.3
Summer	3.3	197	11.1
Autumn			
Annual			

Spring afternoon winds were north-northeasterly 15 percent of the time, while northerly and westerly winds were the second most predominant variety at 14.6 percent. Summer winds were westerly in the morning 43 percent of the time and easterly 19 percent of the afternoons. Fifty-five percent of the summer afternoons experienced winds from either the east or the northeast. Autumn mornings had only west winds 51 percent of the time, while afternoons experienced northerly winds 23 percent of the time.

Winds at 200 M AGL in the morning were in the southern quadrant 50 percent of the time on an annual basis. Least common winds were out of the northeast and east-southeast during the morning hours. Annually, the afternoon winds at 200 M AGL were most common from the north to northeast 39 percent of the time. The prevalent direction for winter morning 200 M winds was from the southeast to southwest (southern quadrant) 61 percent of the time. Afternoon winter 200M winds also were predominantly from the southeast to southwest direction 47 percent of the time. Unfortunately, these southern quadrant winds cause sulfur dioxide problems at Highway Junction. The least common 200 M winds for both winter mornings and afternoons were from the eastern quadrant, which is fortunate as these are the winds that seem to result in high sulfur dioxide levels in Anaconda. Spring 200M winds in the morning generally were from the southern quadrant at a frequency of 58 percent. Afternoon spring 200M winds also were generally from the southern quadrant. Summer morning and afternoon 200 M level winds came from the western quadrant 38 percent of the time and from the northern quadrant 60 percent of the time. The 200 M level winds in the autumn were from the southern quadrant 68 percent of the mornings and from the northern quadrant 42 percent of the afternoons.

The 500 M AGL winds are characterized below:

Mornings	Afternoons
annual - western quadrant @ 46%	western quadrant @ 51%
winter - southern quadrant @ 50%	western quadrant @ 62%
spring - western quadrant @ 48%	western quadrant @38%
summer - eastern quadrant @ 46%	northern quadrant @ 35%
autumn - western quadrant @ 56%	southern quadrant @ 35%

In general, the predominating wind directions at the surface, 200 M AGL, and 500 M AGL correspond well with each other. During plume observations, winds were observed that were very much different at the converter top than at the top of the stack. These occasions are relatively rare, but do exist.

Wind Speed

At the surface and 200 M AGL levels, the morning wind speeds were lower than those from the afternoons. The 500 M level showed a reversal of this trend. The annual average wind speeds for the surface, 200 M, and 500 M levels were 3.2 meters per second, 4.0 meters per second, and 5.9 meters per second, respectively. Annual average wind speeds in the afternoon at the surface were 4.0 meters per second, while the 200 M winds and 500 M winds averaged 7.1 meters per second and 5.2 meters per second. In general, the wind speeds increased with increasing height above ground level, except in the afternoon at 500 meters when the opposite occurred. In every annual average computation, wind velocities from the eastern quadrant were the lowest. This is significant in that the low winds from the east, in conjunction with an inversion, can trap pollutants in the narrow Warm Springs Creek Valley and cause high pollutant concentration levels in Anaconda. Winds from the southern quadrant (in particular from the southwest) proved to be of consistently higher velocities than from other directions. High velocity winds from the southwest have demonstrated that they can cause sulfur dioxide problems at Highway Junction. Diurnal morning and afternoon upper air wind differences are most pronounced at the surface due to the drainage winds the Anaconda area experiences during the mornings. Drainage winds were less pronounced in the winter, and were greatest in the summer.

Surface wind speeds for both mornings and afternoons were greatest in July and least in January, while morning wind speeds at 20 M were greatest in March and least in December. The afternoon 200 M average wind velocities were least in September and greatest in December. Note that at 200 M, winds on December mornings had the lowest velocities and the greatest during afternoons. Velocity of 500-meter winds was highest during December afternoons and lowest during July mornings. The highest morning wind velocities occurred in April, while the lowest afternoon velocities occurred in July.

Temperature Profiles

Temperature profiles of the atmosphere were collected via pilot balloons equipped with a small temperature sounding device. In general, all morning profiles show an inversion condition. The morning profiles also show that above the temperature inversion, the lapse rate is something less than the dry adiabatic lapse rate of -5.5°F/1000 feet. In contrast, the afternoon balloons indicated no inversions, and the afternoon lapse rates were equal to or greater than the standard adiabatic lapse rate.

Mixing Heights

Mixing height information was computed from temperature soundings. Graphically, the mixing height appears as the point where the actual temperature plot crosses the dry adiabatic lapse rate line. Figure 3 demonstrates the monthly average morning and afternoon mixing heights. The average morning mixing heights generally were lowest during the summer and autumn. March, April, May, and December usually experienced the highest morning mixing heights. Afternoon mixing heights also were greatest during the spring, but in contrast to mornings, were lowest during the winter.

As a function of percentage occurrence on an annual basis, 44 percent of all morning mixing heights measured were between zero and 100 meters AGL. The

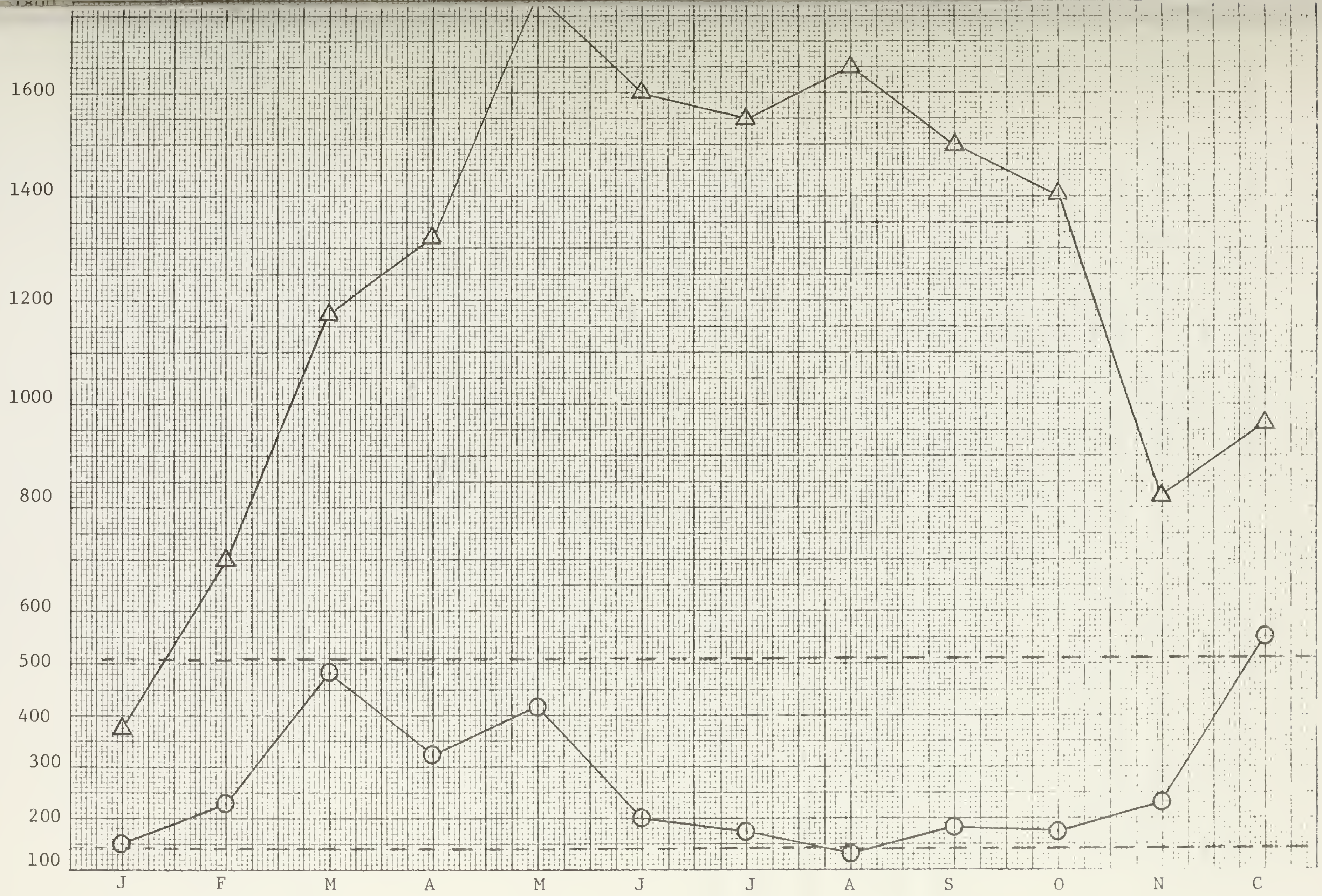


Figure 3 Monthly Average Mixing Heights
Highway Junction, Anaconda, 1979

= AM

= PM

annual total of 84.2 percent of the morning mixing heights measured was 500 meters or less above ground level. Morning mixing heights at 500 meters or cent of the time, while 61.9 percent of the afternoon mixing heights were at 751 meters or greater. Summer afternoon mixing heights were above 1000 meters in 92 percent of the measurements. Winter afternoon mixing heights were above 1000 meters in only 16.1 percent of the measurements.

The mixing heights of significance in the Anaconda area are those that occur between 251 and 500 meters. The Anaconda smelter emission sources lie within these heights. Mixing heights just above the height of each emission source represent entrapment of the pollution below the mixing height in a minimal atmospheric volume for dilution. Theoretically, the months with mixing heights within the 251-500 meter range should experience the greatest number of days with high pollutant levels, and vice versa. January and November are the two months with the greatest percentage occurrence of mixing heights between 251 and 500 meters. Records from all monitoring stations indicate the greatest number of violations of the Montana 0.25 ppm one-hour average standard occurs during August and September. There appears to be very little correlation between mixing height and high sulfur dioxide concentrations. This is not to say that mixing height has no effect on sulfur dioxide concentrations, but it does appear that other confounding variables exist.

Inversions

Inversion information was computed from the temperature soundings performed along with the pilot balloon studies. Inversions were placed in categories determined by the base height and thickness of the inversion. The Holzworth strength clasification system also was used in inversion analysis. Table V explains the Holzworth lapse rate categories for both inversion and non-inversion atmospheres.

TABLE V

Holzworth Lapse Rate Categories (Modified)
Values in deg C/100m

Non-Inversion Class	Lapse Rate	Description
1	-1.60	Very Superadiabatic
2	-1.21 to -1.60	Superadiabatic
3	-0.81 to -1.20	Near Dry Adiabatic
4	-0.41 to -0.80	Near Standard Atmosphere
5	0.00 to -0.40	Weak Lapse

Inversion Class	Lapse Rate	Description
1	0.00 to +0.47	Weak Inversion
2	+0.48 to +1.14	Moderate Inversion
3	+1.15 to ∓2.82	Strong Inversion
4	+2.83 to +6.00	Very Strong Inversion
5	+6.00	Extreme Inversion

(Holzworth, 1974)

Inversions of some type are present virtually all mornings with only 2 to 3 percent without inversions. All but 5.3 percent of the winter afternoons had inversions. In contrast 31.0 percent of the spring afternoons were found to lack inversion conditions. Figure 4 shows the number of occurrences of inversions versus months. Note that the number of inversions is lowest during the spring and highest during fall and winter. It was determined that 80 to 90 percent of the inversions measured had a thickness between one and 250 meters for both mornings and afternoons. Both winter mornings and afternoons showed inversion base heights most often at the range of 251-500 meters AGL. Spring morning inversions were based most often at the surface, while afternoon inversions were based at 1501-2000 meters AGL. Summer and autumn morning inversions also were generally surface based. Summer afternoon inversions were most often based between 1001-1500 meters AGL, while autumn inversions were at 2000 meters AGL or greater.

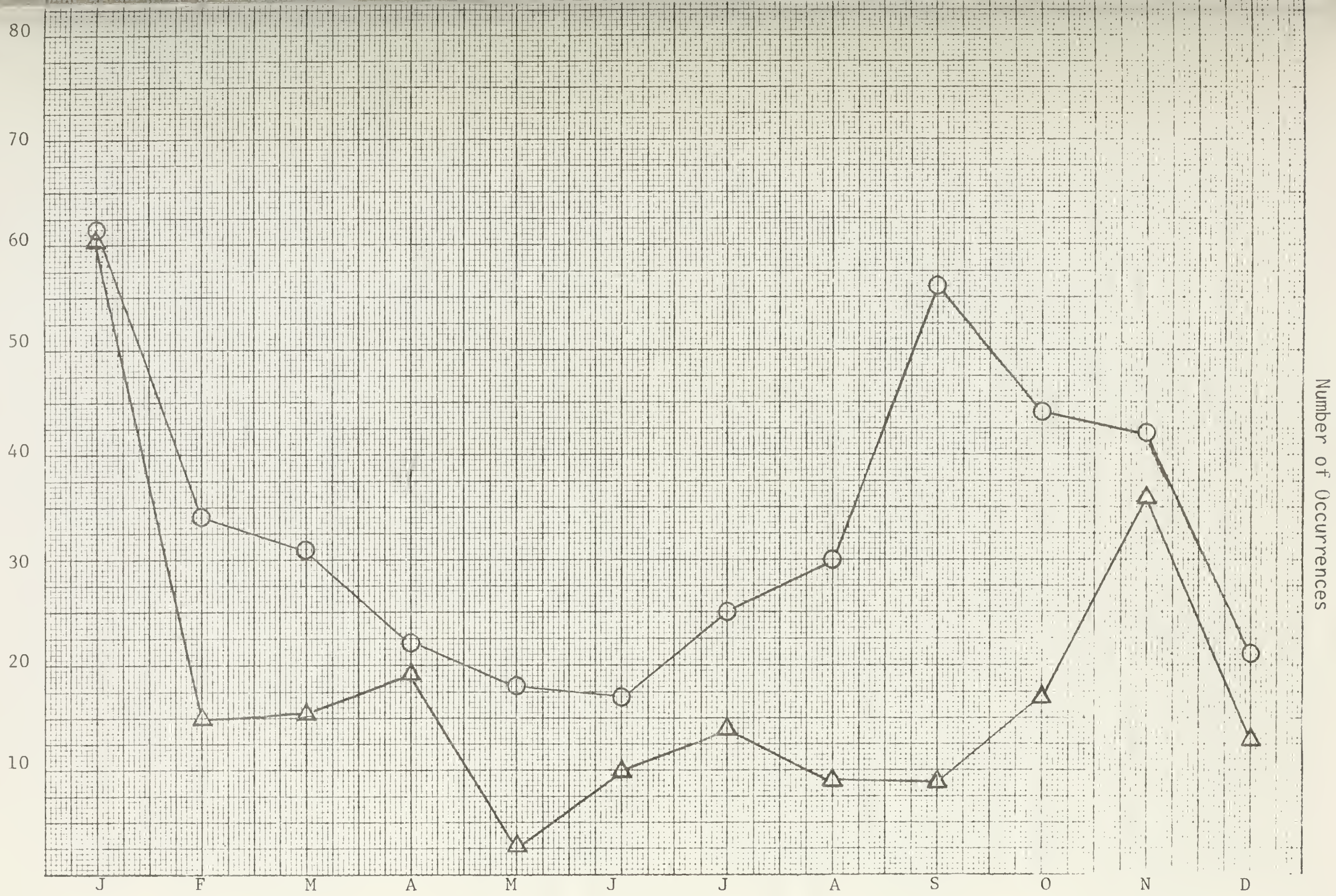


Figure 4 Frequency Summary of Inversions
Highway Junction, Anaconda, 1979

The strongest morning inversions, which were classed Holzworth type 3, occurred during the summer and autumn, with the weakest during spring. The annual average inversion lapse rate was +1.76°C/100m. Afternoon inversions generally were weaker and seasonal averages were all Holzworth type 1 or 2. Autumn and winter had the strongest afternoon inversions, and summer the weakest. The annual average lapse rate below the first inversion was -.77°C/100M in the morning and -1.25°C/100M in the afternoon. The strongest inversions occurred during June and October mornings. The weakest inversions occurred during the afternoons of February and June. Figures 5 and 6 show mean and maximum first inversion lapse rates for mornings and afternoons. In general, the mean and maximum morning lapse rates were lowest in the spring and winter and highest in the summer and fall. The afternoons had the lowest mean and maximum lapse rates during the summer.

In relation to possible effects of inversions on pollution dispersion in the Anaconda area, it appears that the fall and winter would be most conducive to pollution build-up below inversions. This conclusion is due to the findings that in general summer inversions lift to high levels and/or dissipate sometime during the day. In contrast, fall inversions tend to remain intact and undergo less change in strength than do summer inversions.

Stability

Atmospheric stability was determined through interpretation of acoustic radar recordings. Stable events (recorded as inversions) were recorded as to type, formation time, breakup time, lift date, base height, top height, and thickness. Cloud height and cover data were used in stability determinations. (These data were obtained from observations made at the Montana Federal Aviation Administration (FAA) at Butte Airport.) During winter and spring,

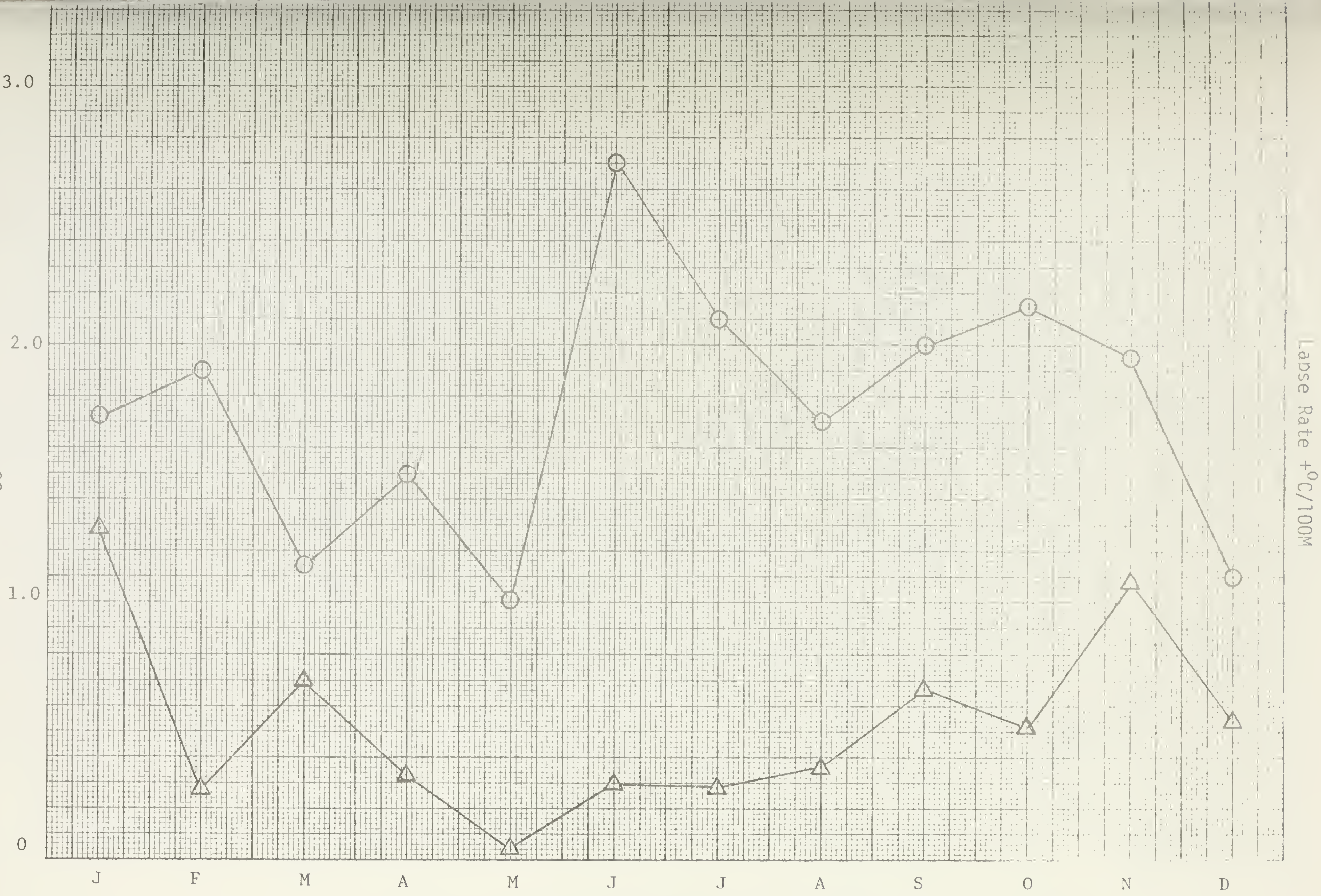


Figure 5 Mean First Inversion Lapse Rates
Highway Junction, Anaconda, 1979

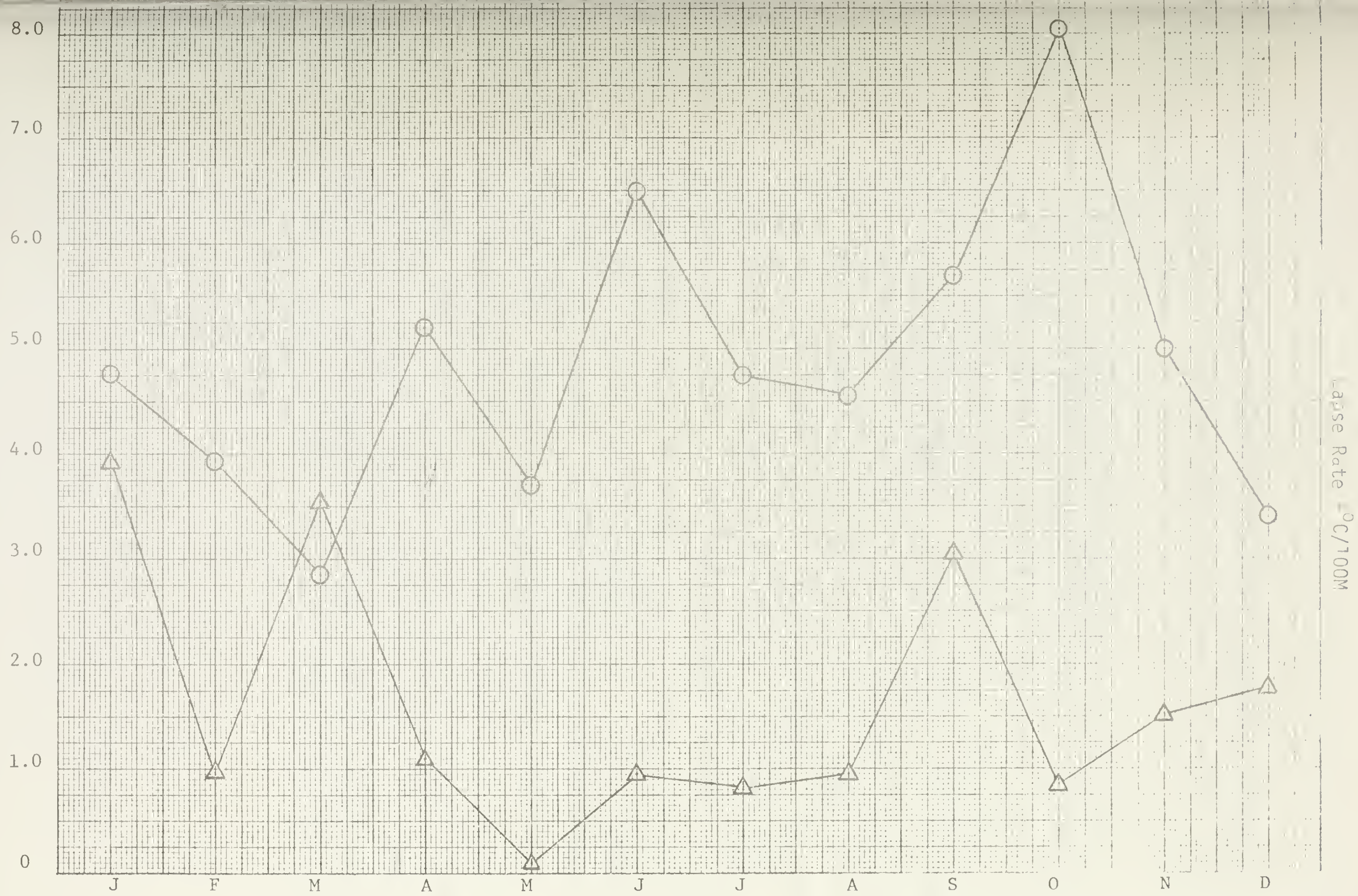


Figure 6 Maximum First Inversion Lapse Rates
Highway Junction, AnacOnda, 1979

meteorological conditions in Anaconda often are very different from those in Butte. In addition, portions of the stability data were not computed due to missing FAA observations.

The vast majority of inversions during all months and seasons was radiational. Frontal and subsidence inversions were uncommon but occasionally did occur in early summer and late fall. Table VI summarizes the occurrence of stable conditions as a monthly, seasonal, and annual average. The seasonal trend is one that follows the expected changes. In general, stable conditions formed earliest during the evening in the winter and latest during the evening in the summer. Stable condition breakup occurred earliest during the summer and latest during the winter, while the stable layer lift rate was greatest in the summer and least in the winter. Stable conditions were longest in duration during winter and shortest during summer, as they persisted during 80 percent of the hours on any given winter day, and 50 percent during the summer. The implications for air stagnation and the resulting possibility of pollution augmentation are apparent. The winter atmosphere is stable one third of the day longer than is the summer atmosphere. Referring to Table VII the numbers of high winter sulfur dioxide readings are 22 percent higher than in summer. This positive correlation between stable period duration and high sulfur dioxide measurements indicates a possible relationship between these two parameters. The correlation also holds for a winter-autumn comparison but breaks down for a winter-spring comparison. One can hypothesize that erratic spring winds and frequent storm fronts cause the spring deviation.

Table VI Summary of Stable Atmospheric Conditions

Anaconda, 1979

Month	Average Formation Time(MST)	Average Lifting Time (MST)	Average Rate of Assent Meters/hour	Average Duration Hours
Jan.	1606	1001	47	18.5
Feb.	1629	1122	91	19.5
Mar.	1822	1032	90	16.0
Apr.	1813	0733	157	13.3
May	1906	0702	106	12.5
Jun.	2020	0735	136	11.3
Jul.	2015	0828	143	11.5
Aug.	1830	0937	141	15.0
Sep.	1920	1026	141	18.5
Oct.	1735	1131	141	18.5
Nov.	1713	1120	125	18.2
Dec.	1938	1500	50	20.0
Winter	1724	1206	63	19.3
Spring	1847	0822	118	13.9
Summer	1955	0833	140	12.6
Autumn	1759	1092	136	17.3
Annual	1822	1023	115	15.8

Table VII

Summary of SO_2 Violations at All Stations

Anaconda, 1979

Month	MT. .25 ppm 1-hr	MT .10ppm 24-hr	National .14 ppm 24-hr	National .50 3-hr	Totals
Jan	74	15	7	10	106
Feb	54	10	3	3	70
Mar	61	14	4	6	85
Apr	0	0	0	0	0
May	19	2	0	1	22
Jun	56	11	3	8	78
July	67	9	2	6	84
Aug.	98	15	6	10	129
Sept.	87	19	3	8	117
Oct.	59	9	4	7	79
Nov.	13	3	0	1	17
Dec.	134	26	14	22	196
Winter	262	51	24	35	372
Spring	80	16	4	7	107
Summer	221	35	11	24	291
Autumn	159	31	7	16	279
Annual	722	133	46	82	983

Second inversions were uncommon for all months and seasons, with winter and early spring recording the most second inversions, 8 to 9 percent of the time. During summer and fall, second inversions occurred only 4 to 5 percent of the time. Second inversions generally had a base height of 300 to 400 meters and were 100 to 200 meters thick. Although second inversions occurred infrequently, they were high enough in elevation to trap the smelter's emissions between the first and second inversions, thus, in effect, decreasing the ground-level concentrations of pollutants.

Neutral atmospheric conditions were common but short in duration. Summer experienced the greatest number of neutral atmospheric periods, although they usually lasted only one to three hours just prior to and following sunset. Winter records showed the fewest number of neutral periods, although they were longer in duration, with four to six hours not uncommon.

Unstable atmospheric conditions were most often recorded during the summer, autumn and late spring. These occurrences generally were associated with thermal updrafts caused from surface heating and radiation. Unstable conditions during the winter generally were associated with storm fronts, and occasionally thermals on days when little snow cover was present. Balloon runs during afternoons in summer and fall often were disrupted by thermal updrafts, which carried the pilot balloons aloft at a rate much greater than the intended rate. These days were observed to be favorable for ample plume rise and dispersion.

Meteorology and Air Monitoring

The purpose of this section is to determine time periods and environmental conditions that correspond with high ambient concentrations of sulfur dioxide.

Table VII summarizes the various air quality standards, including the number of times they were violated each month during 1979. December had the

highest sulfur dioxide readings followed by August. December experienced the greatest number of three-hour periods with .50 ppm average concentrations, i.e., the greatest and most severe number of SO_2 incidences. April recorded no incidences, and November also was low. The seasonal totals reflect the monthly trends, with winter having the most violations and spring the fewest.

A more specific analysis of data from two ambient air monitoring stations yields valuable information. Figure 7 shows a graphical analysis of sulfur dioxide concentrations above .25 ppm hourly versus wind direction at Highway Junction.

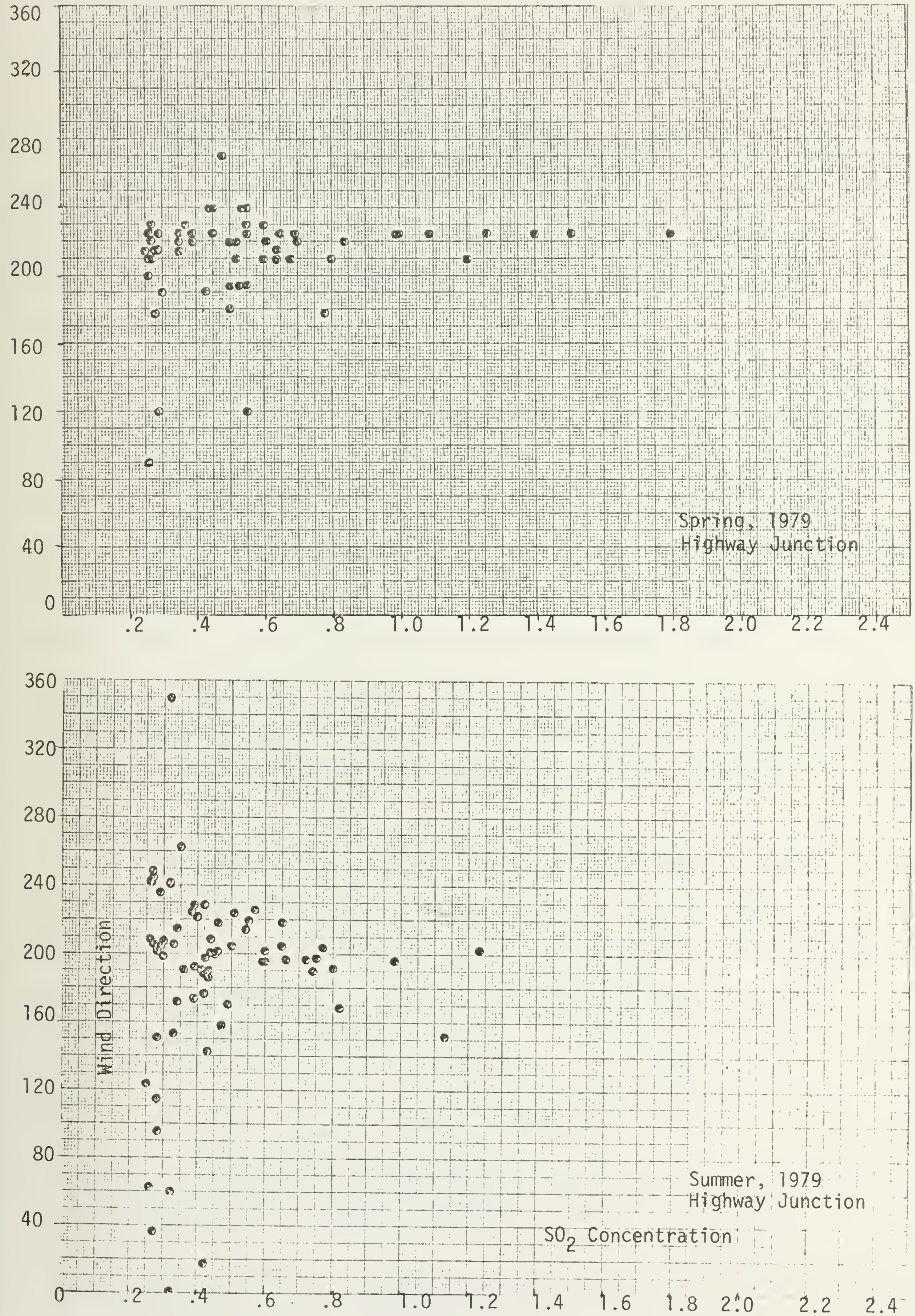


Figure 7 SO_2 Concentrations as a Function of Wind Direction Highway Junction, Anaconda, 1979

III. CASE STUDIES

Two case studies are presented in this section to demonstrate meteorological conditions that cause ground level sulfur dioxide concentrations in excess of state and federal ambient air quality standards. This section also compiles meteorological and ambient air quality data for comparison with results of dispersion models.

Figures 8 and 9 facilitate understanding of smelter and pollution control processes. Figure 8 shows the three main processes responsible for the emission of sulfur dioxide as a byproduct. The fluid bed roaster, the electrical furnace, and the converter furnaces are the primary process sources, shown in Figure 8. The main stack is the largest emission source with a flow rate of 236 m^3/sec (300,000 scfm) containing about 490 g/sec (11,800 lb/hr) SO_2. The two acid plant stacks are other major sources of emissons with a combined flow of 40.2 m^3/sec (85,000 scfm) carrying 114g/sec (907 lb/hr) SO_2. The converter building is the final major source of sulfur dioxide emissions with a flow of 1,230 m^3/sec (2,610,000 scfm), containing 250 g/sec (2,000 lb/hr) SO_2.

A. Case I

During 29-30 August 1979, "Air Quality Stage 2 Alert" conditions were reached in Anaconda. Table VIII lists and explains the various stages of an emergency episode. The Lincoln School ambient air monitoring station recorded sulfur dioxide concentrations up to 4.21 ppm hourly average with peak concentrations greater than 5.0 ppm.

Table VIII

Stages of Emergency S02 Episode

Pre alert: (0.25 ppm SO_2 24-hour average)
A level at which the Anaconda company will notify the Air Quality Bureau of a pending emergency episode condition.

Alert: (0.30 to 0.50 ppm SO_2 24-hour average)
An EPA established level calling for reduced industrial activity and curtailment of public exposure to sulfur dioxide gas.

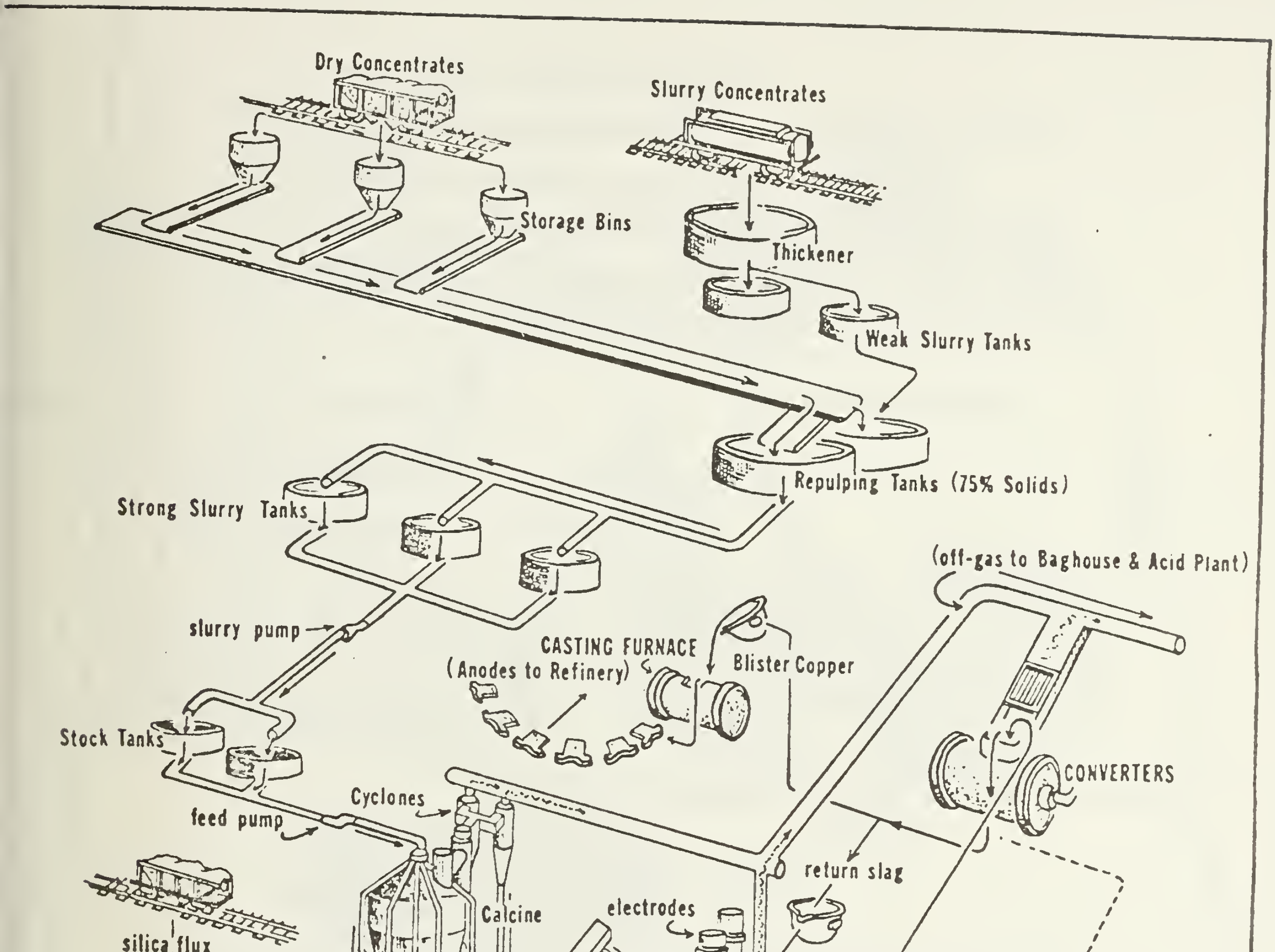

Dry Concentrates
Slurry Concentrates
Storage Bins
Thickener
Weak Slurry Tanks
Repulping Tanks (75% Solids)
Strong Slurry Tanks
(off-gas to Baghouse & Acid Plant)
slurry pump
CASTING FURNACE
(Anodes to Refinery)
Blister Copper
Stock Tanks
CONVERTERS
Cyclones
feed pump
return slag
Calcine
electrodes
silica flux
copper matte
FLUID BED ROASTER
Pre-Heater
(flux by-pass)
Converter cleanings
Blower
ELECTRIC FURNACE
waste slag
FEED PREPARATION AND SMELTING
PROCESS FLOW
mobile slag pot carrier

Figure 8

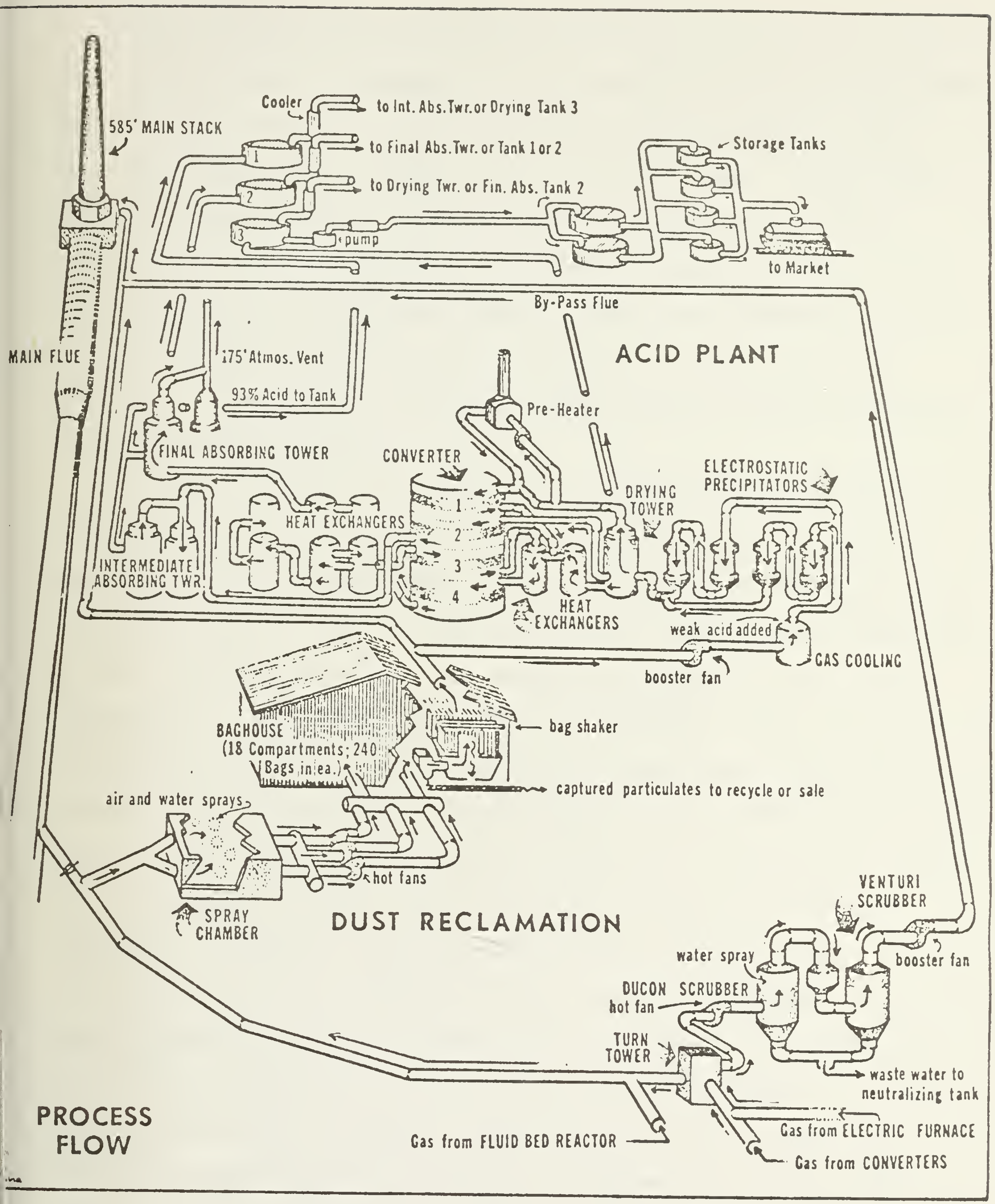

Cooler
to Int. Abs. Twr. or Drying Tank 3
585' MAIN STACK
to Final Abs. Twr. or Tank 1 or 2
Storage Tanks
1
2
to Drying Twr. or Fin. Abs. Tank 2
3
pump
to Market
By-Pass Flue
MAIN FLUE
175' Atmos. Vent
ACID PLANT
93% Acid to Tank
Pre-Heater
FINAL ABSORBING TOWER
CONVERTER
ELECTROSTATIC PRECIPITATORS
DRYING TOWER
1
HEAT EXCHANGERS
2
3
INTERMEDIATE ABSORBING TWR.
4
HEAT EXCHANGERS
weak acid added
GAS COOLING
booster fan
bag shaker
BAGHOUSE (18 Compartments; 240 Bags in ea.)
captured particulates to recycle or sale
air and water sprays
hot fans
VENTURI SCRUBBER
SPRAY CHAMBER
DUST RECLAMATION
water spray
booster fan
DUCON SCRUBBER
hot fan
TURN TOWER
waste water to neutralizing tank
PROCESS FLOW
Gas from FLUID BED REACTOR
Gas from ELECTRIC FURNACE
Gas from CONVERTERS

Figure 9

Figure 10 shows sulfur dioxide concentrations as a function of wind direction at Lincoln School in Anaconda. A cursory review of these graphs indicates that wind direction does not affect sulfur dioxide concentrations at Lincoln School when compared to the Highway Junction data. The summer and autumn data points show some correlation to wind direction, but winter and spring data points, on the contrary, show little correlation. A possible explanation for this phenomenon is that Anaconda's location in Warm Springs Creek Valley causes complex wind patterns allowing pollutants to enter the valley from various directions. This seems to be the case, as winter and spring winds are the most variable and reach the highest velocities.

The summer and autumn data indicate some dependence upon wind direction, which could be associated with the occurrence of light and variable easterly winds prevalent during these seasons. Another explanation for the random nature of the data points is that air stagnation conditions could cause an accumulation of sulfur dioxide in the valley, thus leading to high ambient sulfur dioxide concentrations. This phenomenon appears to be independent of wind direction. An examination of the data tends to support this explanation. Virtually all readings of high sulfur dioxide at Lincoln School occurred between 0600 MST and 1300 MST, which generally is the time that surface-based inversions would have lifted to a level just above the emission sources, trapping the pollutants underneath. In addition to the time characteristic, it appears that all but a few of the sulfur dioxide readings were associated with winds below four meters/sec, but usually below two or three meters/sec. The authors feel that the Lincoln School site and the city of Anaconda experience high sulfur dioxide levels primarily related to stagnant air and inversion conditions, rather than wind direction, in contrast to the Highway Junction site, which appears to experience high sulfur dioxide conditions dependent on wind direction and be independent of inversions and stagnant air. Neither explanation is

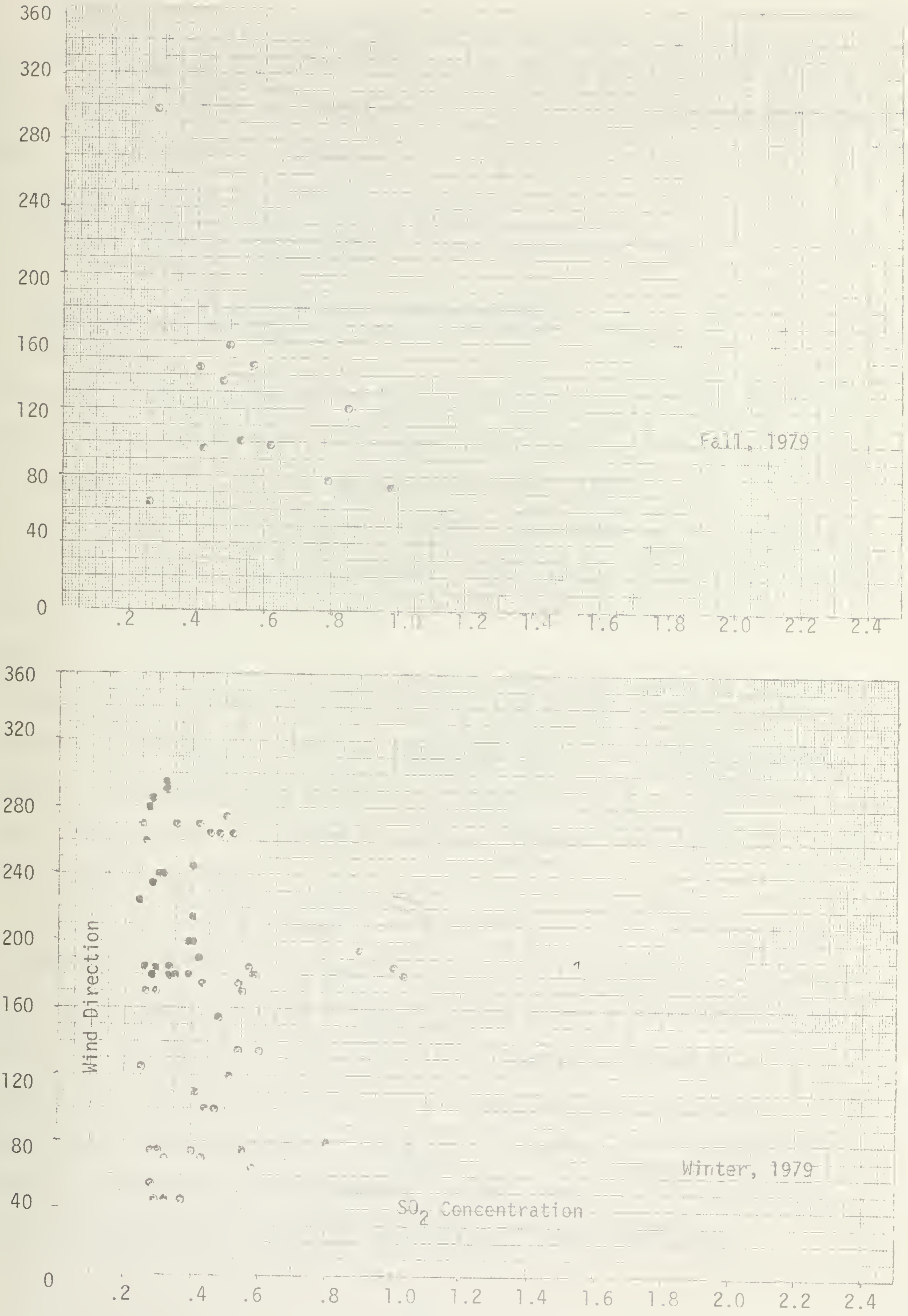


Figure 10 SO_2 Concentrations as a Function of Wind Direction
Lincoln School, Anaconda, 1979

absolute. Occasional incidences not falling within the general pattern also have occurred. However, more often than not, the situations discussed herein do apply to sulfur dioxide incidences.

> Warning: (0.50-0.80 ppm SO_2 24-hour average)
> An EPA established level mandating industrial operation be curtailed to a standby status, and additional curtailment of human exposure to the gas.
>
> Emergency: (0.80 plus ppm SO_2 24-hour average)
> Industrial operation shutdown and maximum reduction in human exposure.

The highest 24-hour average concentration level was 0.44 ppm. Table IX lists the hours of the alert, hourly SO_2 concentrations, running 24-hour average SO_2 concentration, wind speed, and wind direction at Lincoln School.

On 28 August, the 0500 MST surface weather chart indicated the presence of a cold front in southern Alberta with general high pressure throughout the western United States. During the 29th a high pressure system formed in western Montana, and the cold front had become stationary in the northeastern part of the state. The high pressure system induced light easterly winds and air stagnation in the mountain valleys. During the 30th the high pressure system dissipated and a surface low formed in northwestern Montana as an upper level trough moved in from the southwest. The winds increased and switched to a southwesterly direction.

The acoustic radar at Highway Junction recorded a surface based inversion at 1900 MST on the 28th. The inversion persisted until 1100 MST on the 29th, at which time it began lifting at a rate of 125 m/hr. Inversion formation on the 29th was at 1800 MST and ended abruptly the following day at 0900 MST. The wind direction at high concentration periods (.25 ppm) was between 80 and 150 degrees, while the wind speed was low at 0 to 2.2 meters/sec. The wind angle impacting Lincoln School with respect to the main stack was 122°and 105° with respect to the converter building. The prevailing wind direction was

Table IX

Lincoln School Sulfur Dioxide Concentration and Wind Behavior

Day	Hour	Hourly Average SO_2 Concentration	Running 24-Hour Average SO_2 Concentration	Wind Direction at Lincoln School	Wind Speed (m/s) at Lincoln School
Aug 29	0-1	0.07		275	4.0
	2	0.11		280	4.9
	3	0.12		290	4.9
	4	0.14		285	4.9
	5	0.1		275	4.0
	6	0.15		270	3.6
	7	0.13		280	2.7
	8	0.13		290	3.1
	9	0.17		290	0.9
	10	0.57		95	0.9
	11	4.21		120	1.3
	12	1.80		80	2.2
	13	0.74	0.356	80	1.8
	14	0.60	0.381	95	1.8
	15	0.140	0.387	85	1.8
	16	0.027	0.388	98	1.8
	17	0.009	0.388	70	2.7
	18	0.048	0.390	45	1.3
	19	0.081	0.393	210	2.2
	20	0.363	0.407	125	1.3
	21	0.440	0.426	280	2.2
	22	0.123	0.431	280	3.1
	23	0.084	0.434	280	3.1
	24	0.066	0.436		3.6
Aug	1	0.055	0.431	280	4.0
	2	0.037	0.433	280	4.5
	3	0.026	0.429	280	4.5
	4	0.023	0.424	280	3.6
	5	0.023	0.418	280	3.6
	6	0.023	0.413	275	3.1
	8	0.020	0.404	280	2.7
	9	0.037	0.398	230	0.4
	10	0.258	0.385	150	0.4
	11	0.263	.221	95	0.9
	12	0.085	0.149	205	3.1

120° during the highest hourly sulfur dioxide concentration measurement of the alert. This measurement exemplifies the correlation between wind direction and sulfur dioxide concentration.

Two balloons were released on 29 August, a morning balloon at 0622 MST and an afternoon balloon at 1400 MST. The morning balloon recorded three inversions. (The first inversion was a strong surface-based inversion, 320 meters thick, with a lapse rate of +1.153°C/100M. The second inversion, 105 meters thick, had a base height of 375 meters AGL, and a moderate inversion lapse rate of +0.743°C/100M. The final inversion had a base height of 910 meters AGL, was 55 meters thick and moderate at +0.743°C/100M.) The morning mixing height was 113 meters and the average wind speed through the mixed layer was 1.8 m/sec. The wind barbs in Figure 11 show the wind speed and direction at various levels throughout the first 2000 M AGL.

The afternoon balloon also indicated the existence of three inversions. The first was based at 750M AGL with a thickness of 55M and a weak inversion lapse rate of +0.187°C/100 M. The second inversion had a base height of 1075M AGL, a thickness of 55 meters and a moderate strength of +0.561°C/100 M. The third inversion was based at 1230M AGL, 105M thick and had a lapse rate of +0.187°C/100 M. The average wind speed through the mixed layer was 4.3 M/sec. The wind barbs in Figure 11 depict the wind speed and direction throughout the atmosphere in the afternoon.

The morning (0622 MST) wind barbs at the lower heights indicate the westerly Warm Springs Creek drainage winds typical of morning wind conditions during the summer. The afternoon balloon run indicated light winds from the east, at approximately the correct angle for volume impact on Lincoln School. Figure 12 shows vectors of prevailing wind direction and magnitude at each of the monitoring stations on 29 August at 1100 MST, when sulfur dioxide concentrations were peaking at greater than 5.0 ppm.

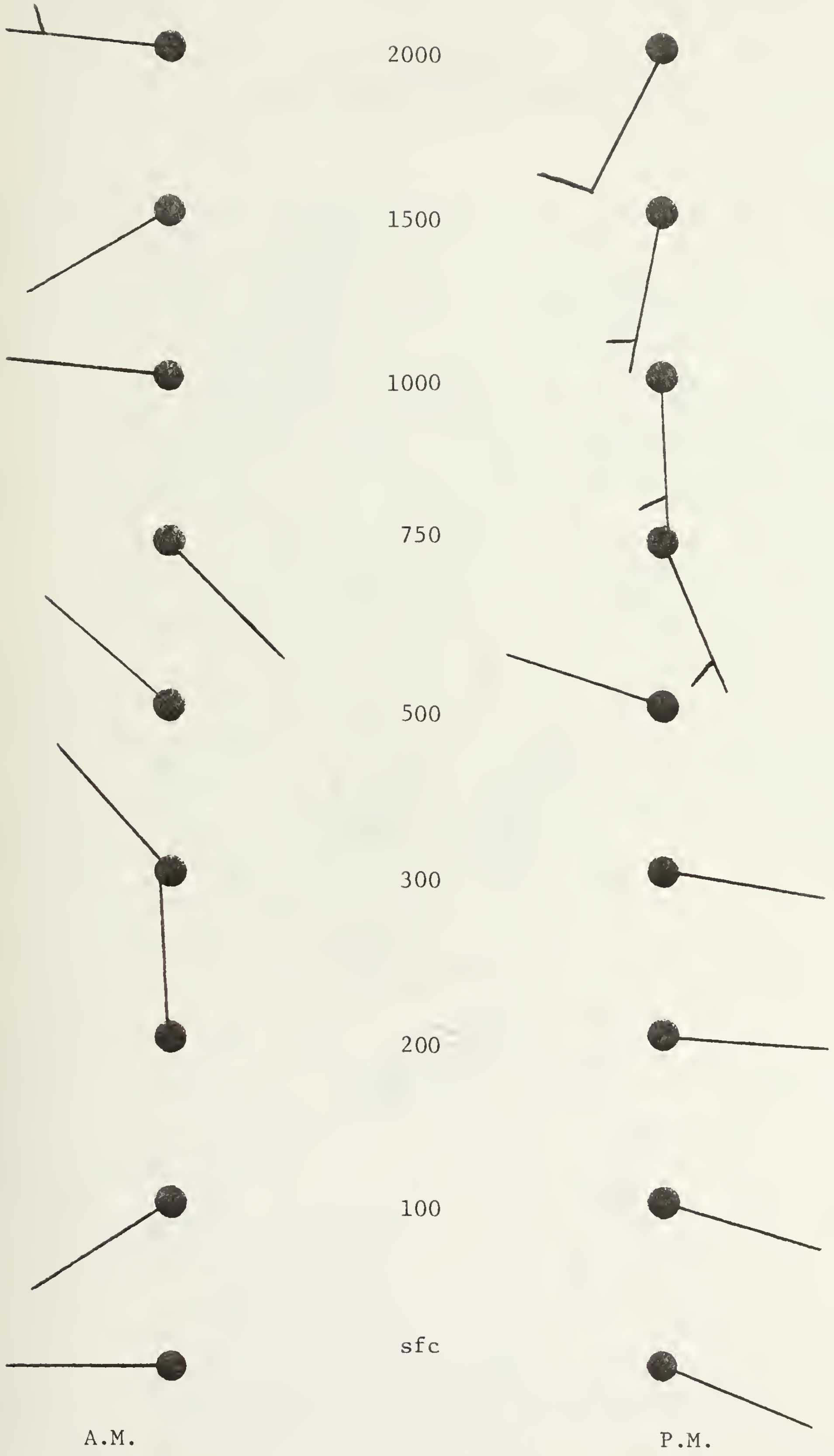
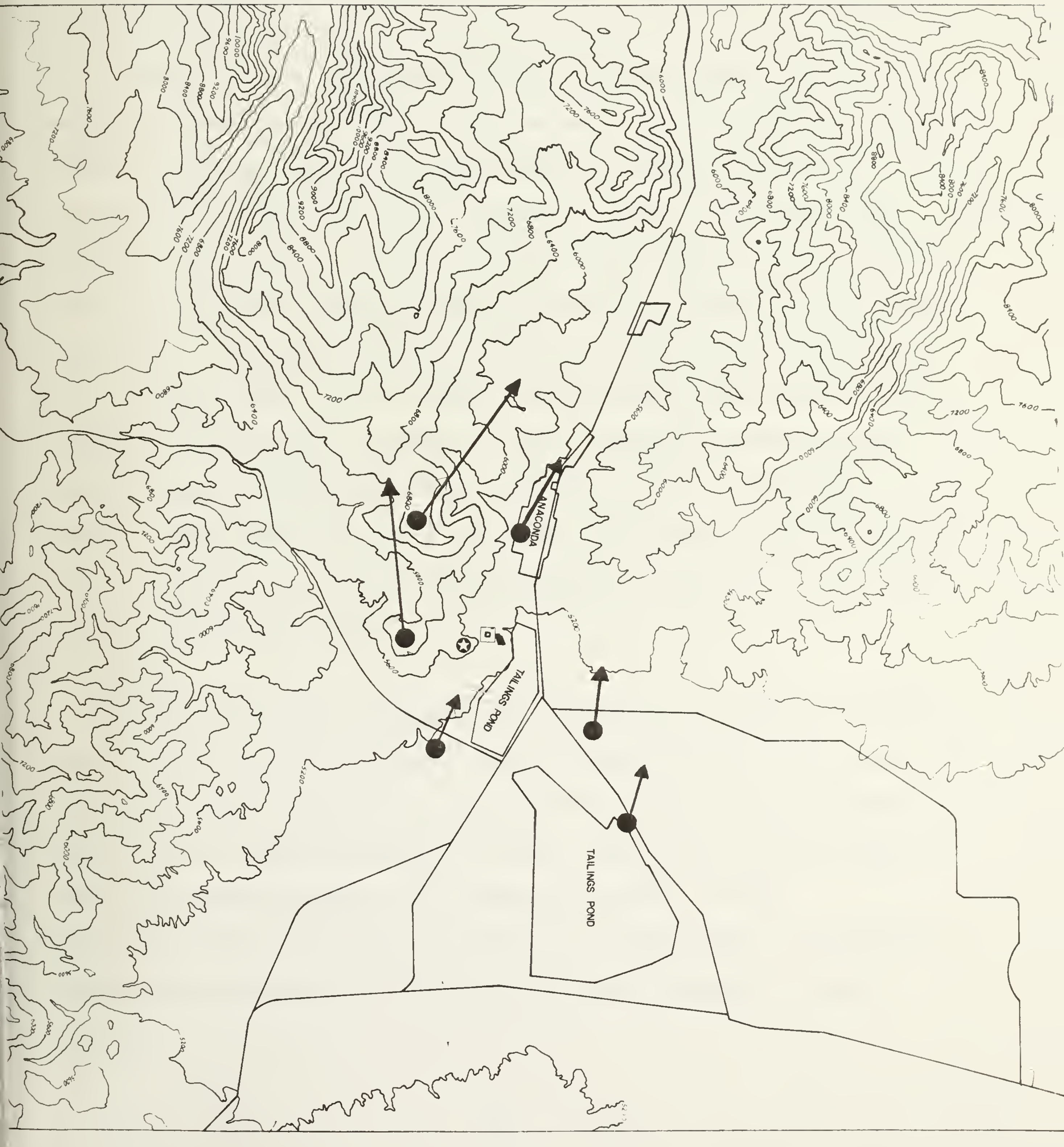


Figure 11

Figure 12
Wind Vectors for 29 August 1979



The Mill Creek and Lincoln School vectors show the low speed winds that swept the sulfur dioxide throughout the Warm Springs Creek Valley. The topography played an important role in the alert as the pollutants' horizontal movement was impeded by both the steep valley walls and the inversion's vertical movement, resulting in a small relatively enclosed air mass in which the sulfur dioxide was mixed and diluted.

In summary, the air quality alert in this case study seems to have developed in the following manner. Light easterly winds in combination with an inversion condition in the early morning caused no problems because the SO_2 emissions were above the first inversion. At around 1000-1100 MST the inversion lifted enough to trap the plume below the inversion; in turn, the persistent light easterly winds blew the sulfur dioxide into Anaconda causing the high readings from 1000 to 1200 MST on the 29th. As the inversion kept rising to its afternoon level, the SO_2 concentrations decreased, until 2000 MST when the evening inversion again trapped the sulfur dioxide and elevated ambient concentrations. At 2200 MST the wind increased in velocity and switched direction, thus clearing the air at Anaconda. On the 30th at 1000-1100 MST the winds switched back to light easterlies, causing a situation similar to that of the 29th although less severe.

B. Case II

The Anaconda Company's Highway Junction station experienced an Air Quality Stage 2 alert on 23 and 24 October. The sulfur dioxide hourly average concentration reached a maximum of 1.16 ppm at 2200 MST on the 22nd, while the running 24-hour average concentration reached a maximum of .42 ppm. Table X lists the following parameters with regard to this alert: hourly SO_2 concentrations; running 24-hour average SO_2 concentrations; running 24 hour average SO_2 concentrations; and wind speed, and wind direction at Highway Junction.

The synoptic situation was characterized by the presence of a stationary front in extreme western Montana associated with a low pressure system on 22 October. By 23 October the front had moved to the eastern portion of the state, while a high pressure system was moving in from the south, as a weak cold front moved through the southwestern corner of Montana. During 24 October the front had moved out of the state and a high pressure system was centered over western Montana. Both 22 and 24 October saw trace amounts of precipitation in the Anaconda area.

The acoustic radar at Highway Junction recorded the formation of a surface-based inversion at 1630 MST on 22 October. This inversion remained until 1000 MST the next day, when it dissipated. During the evening of 23 October an inversion formed at 1700 MST, lifting the following date at a rate of 100 M/hr. Table XI indicates a poor correlation between the presence of an inversion and the occurrence of high SO_2 concentrations. The wind direction during periods of high SO_2 concentrations (.25 ppm) averaged about 191°, which correlates well with the calculated wind angles impacting the station at 210° for the stack and 222° for the converters. The two highest respective hourly SO_2 averages of 1.14 ppm and 1.16 ppm showed prevailing wind directions of 204° and 197°.

Two balloons were released on 23 October at 0735 MST and 1400 MST. Two balloons also were released on 24 October, at 0737 MST and 1400 MST. The morning balloon run of 23 October recorded one surface-based inversion 107 meters thick and a moderate inversion lapse rate of +0.654° C/100 M. The morning mixing height was 445 M and the wind speed through the mixed layer was 5.0 M/sec. The afternoon sounding revealed three inversions with the following characteristics:

Table X

Highway Junction Sulfur Dioxide Concentration and Wind Behavior

Day	Hour	Hourly Ave. SO_2 Concentration	Running 24-Hr. Average SO_2 Concentration	Wind Direction at Highway Junction	Wind Speed (m/s) at Highway Junction
Oct. 22	19	0.18	0.06	211	9.8
	20	0.23	0.06	212	12.5
	21	0.82	0.10	209	13.0
	22	0.72	0.13	201	10.7
	23	1.16	0.18	197	9.8
	24	0.50	0.20	202	8.5
Oct. 23	0-1	0.25	0.21	203	8.0
	2	0.35	0.22	210	7.6
	3	---	---	198	8.0
	4	---	---	200	6.7
	5	0.00	0.24	206	6.7
	6	0.00	0.24	204	6.7
	7	0.00	0.23	204	6.3
	8	0.02	0.23	212	4.5
	9	0.51	0.25	206	4.0
	10	0.66	0.28	207	3.6
	11	0.63	0.31	178	3.6
	12	1.14	0.36	204	4.0
	13	0.64	0.39	199	4.5
	14	0.20	0.39	199	3.6
	15	0.40	0.41	144	0.9
	16	0.17	0.42	209	0.9
	17	---	---	266	2.2
	18	0.04	0.41	259	1.8
	19	0.06	0.41	249	4.0
	20	0.12	0.40	238	3.6
	21	0.08	0.37	239	3.1
	22	0.09	0.34	241	1.8
	23	0.10	0.29	138	0.4
	24	0.11	0.27	149	0.9
Oct. 24	1	0.10	0.26	---	0
	2	0.10	0.25	---	0.5
	3	0.10	0.25	274	0
	4	0.10	0.25	235	0.9
	5	0.11	0.24	248	1.3

TABLE XI

Inversions and SO_2 Concentrations

Inversion base (M AGL)	Thickness (M)	Lapse Rate (^oC/100M)
1405	85	0.726
2725	165	0.303
2975	165	0.182

Inversions detected on 24 October had the following characteristics:

	Inversion base (M AGL)	Thickness (M)	Lapse Rate (^oC/100M)
AM	0.0	107.0	0.654
	480	160	0.810
PM	990	80	0.363

This case, and in general most SO_2 incidents at Highway Junction, showed little cause-effect relationship between high SO_2 readings and the presence of an inversion.

The wind barbs in Figure 13 show wind speed and direction for various levels throughout the atmosphere as determined by pilot balloons. The morning run of 23 October shows the wind speed and direction relatively constant from the southwest (220°) up to the 750 M level, where it shifted to the southeast. At 1000 meters the wind reshifted to the southwest. The afternoon balloon run indicated southwest winds up to 500 M where a change to the east-southeast was recorded. Above 500 M the wind came from the west or southwest. The balloon runs on 24 October indicated winds from the south and southwest in the morning and from the southeast at low heights to southwest at upper levels in the afternoon (Figure 14). Figure 14 shows vectors of prevailing wind direction and magnitude at each of the monitoring stations during 1200 MST when sulfur dioxide concentrations were peaking at greater than 2.0 ppm. The variable wind speeds and divergent wind directions indicate the complexity of the wind

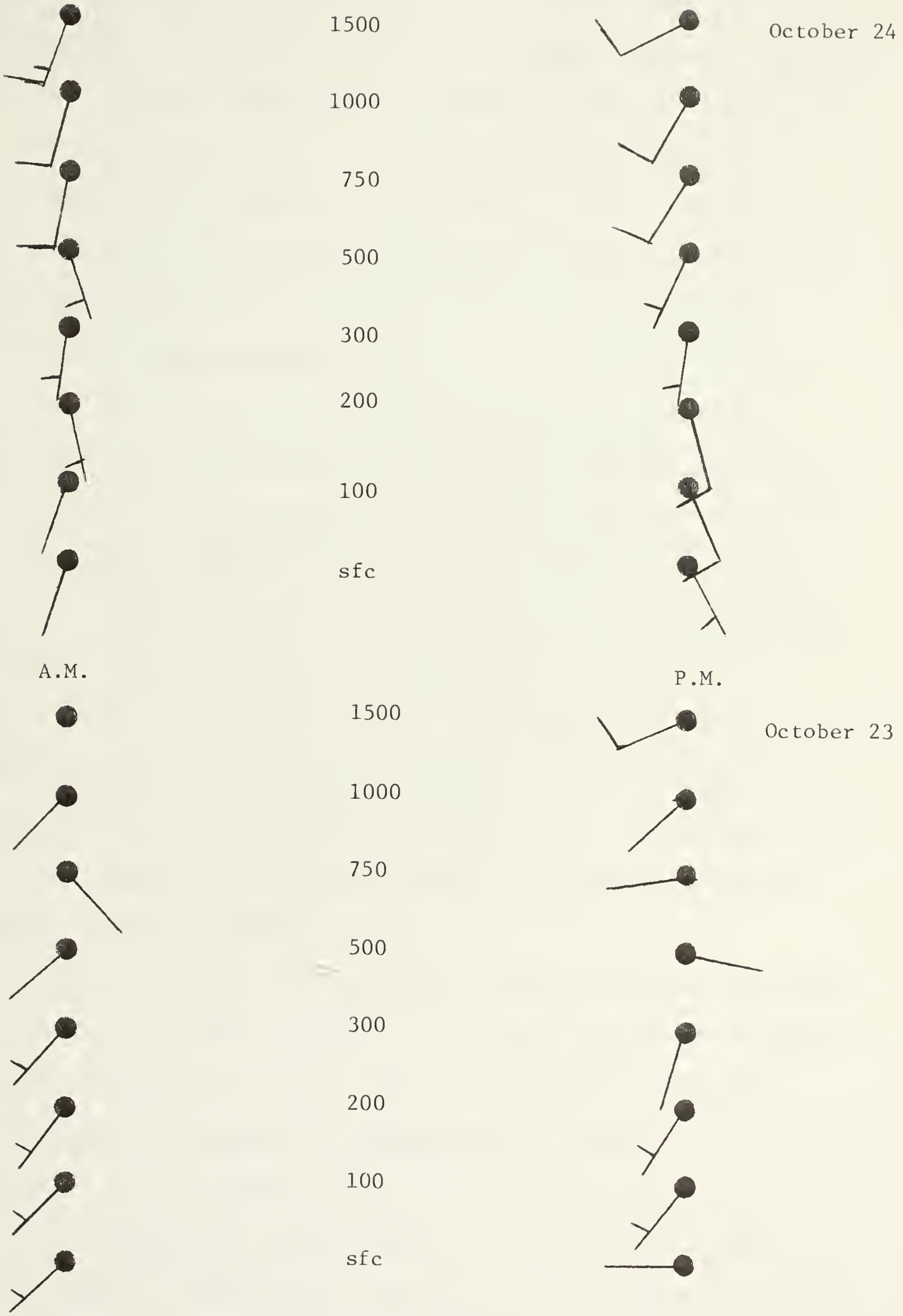


Figure 13

Upper air wind speed and direction

runs on 24 October indicated winds from the south and southwest in the morning and from the southeast at low heights to southwest at upper levels in the afternoon (Figure 14). Figure 14 shows vectors of prevailing wind direction and magnitude at each of the monitoring stations during 1200 MST when sulfur dioxide concentrations were peaking at greater than 2.0 ppm. The variable wind speeds and divergent wind directions indicate the complexity of the wind systems in the Anaconda area that are responsible for high ground level SO_2 concentrations at Highway Junction.

In summary, the air quality alert in this case developed as follows. During the late evening of 22 October the wind switched from the southeast to a southwesterly direction and increased in velocity, which resulted in high sulfur dioxide levels at Highway Junction between 1900 MST on the 22nd and 0200 MST on the 23rd. The wind velocity decreased about 0300 MST and the SO_2 levels dropped to zero as converter furnace operations were curtailed. At 0900 MST the Anaconda Company decided to resume operation. At the same time, the SO_2 levels at Highway Junction jumped to .50 ppm and averaged .72 ppm for the next five hours. A curtailment of smelter operations dropped the SO_2 levels until wind direction and speed changed during the early hours of 24 October ending the alert and resuming smelter operations.

Observations lead to the following analysis of how the Anaconda topography causes the SO_2 alerts at Highway Junction. At high wind velocities a downwash condition is induced behind the stack. Figure 15 is a photograph of this condition, while Figure 16 diagrams this phenomenon. In addition to stack downwash, it appears that as southwest winds blow over the crest of the C-Hill and Weather Hill, a condition is created whereby the stack plume is carried to the ground as in Figure 16. High winds from the southwest, combined with the above phenomenon, result in sulfur dioxide problems directly downwind at Highway Junction.

Figure 14
Wind Vectors for 24 October 1979

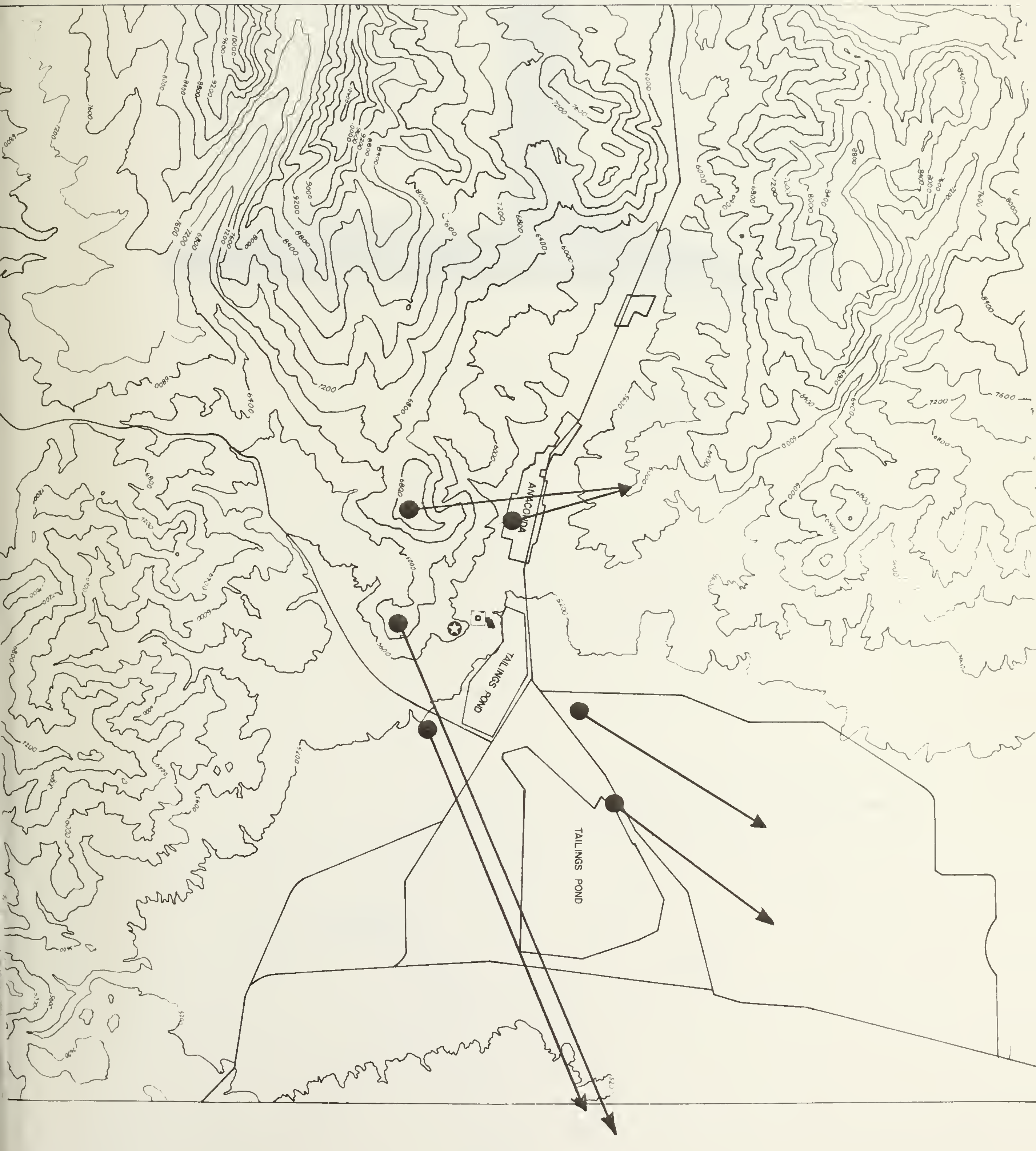


Figure 15

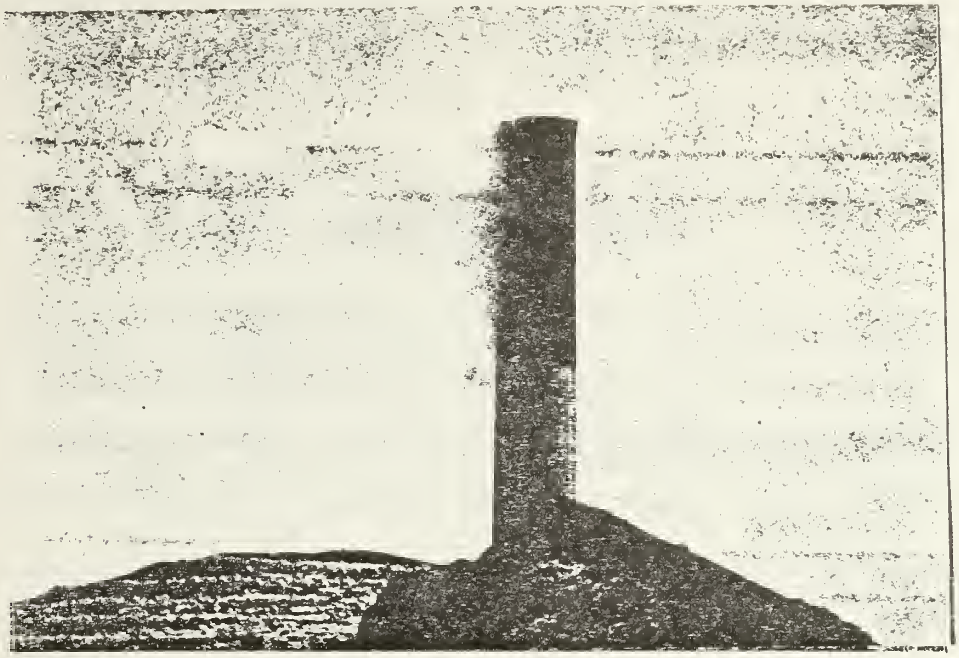
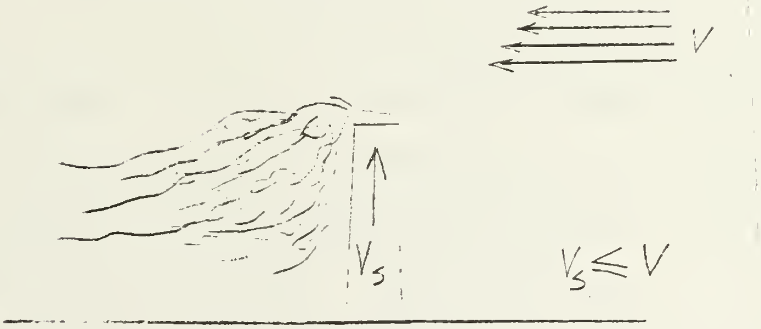
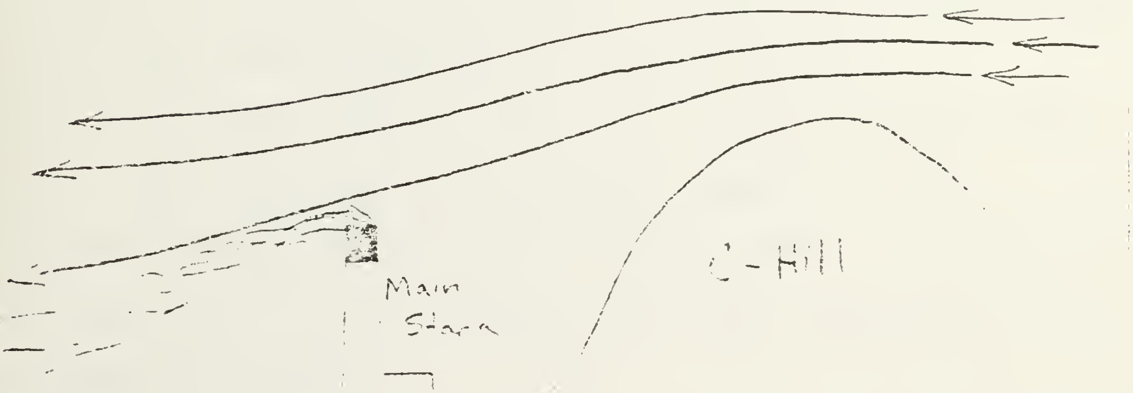


Figure 16





IV. SUMMARY AND CONCLUSIONS

In summary, some general trends about meteorological conditions in the Deer Lodge Valley have been revealed through analysis of the available data. It is recognized that the area's meteorology is extremely complex, but two major meteorological conditions accentuate pollution episodes. At Lincoln School in Anaconda, high sulfur dioxide measurements are associated primarily with air stagnation and atmospheric temperature inversions. A secondary factor in these events is the presence of light easterly winds. At Highway Junction northeast of Anaconda, high sulfur dioxide measurements are primarily a function of strong southwesterly winds. A secondary factor is the presence of an upper atmospheric stable layer or temperature inversion. Personal observations and much of the data collected during sulfur dioxide episodes at Highway Junction (see case study II) reveal very different wind directions at the top of both the smelter's stack and the converters. The wind direction at the top of the converters coincides with the direction necessary for air pollution impacts at Highway Junction, although the stack wind direction does not coincide. Further study and data analysis are required to identify and to verify this condition. These wind phenomena indicate that the converters may be a primary cause of high sulfur dioxide ground level concentrations for both case studies.

Although sulfur dioxide alerts are known to be associated with the above meteorological events, the presence of such weather conditions has not necessarily dictated the occurrence of a sulfur dioxide alert. This volume of information should assist greatly in the modeling of plume dispersion to resolve pollution problems in the area.

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